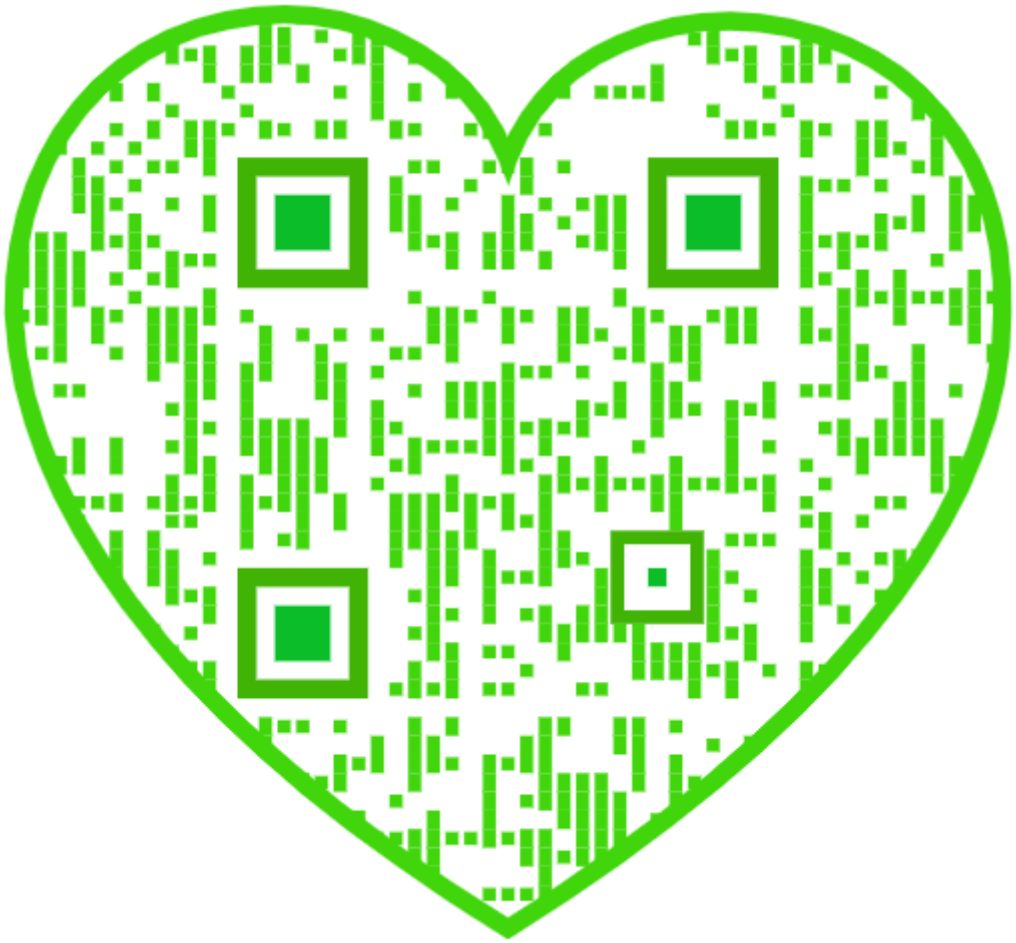

OPERATIVE MASONRY:

OR,

A THEORETICAL AND PRACTICAL

TREATISE OF BUILDING;

CONTAINING

A SCIENTIFIC ACCOUNT OF STONES, CLAYS, BRICKS, MORTARS, CEMENTS, &C.; A DESCRIPTION OF THEIR COMPONENT PARTS, WITH THE MANNER OF PREPARING AND USING THEM.

The Fundamental Rules in Geometry,

ON

MASONRY AND STONE-CUTTING,

WITH THEIR APPLICATION TO PRACTICE.

ILLUSTRATED WITH FORTY COPPER-PLATE ENGRAVINGS.

BY EDWARD SHAW, ARCHITECT,
Author of Civil Architecture, &c.

BOSTON:
MARSH, CAPEN & LYON.
1832.

Eng 628.32

Entered according to Act of Congress in the year 1832, by
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PREFACE.

In preparing this work for the public, it has been the design of the Compiler to avoid prolixity, by the rejection of such things as are already known to the mechanic, and to furnish him with a knowledge of the principles and facts, on which he might be supposed to require information.

Most works on this subject, set out with a description of all the minutiæ of the art of building; and though they may, perhaps, exhibit something that will be useful to the apprentice, yet they contain much that is of no importance to the practical mechanic; while the price is so much enhanced, that few can well afford to possess them.

As permanency in building seems, at the present day, to be an object more desirable than formerly, it has been thought that a brief account of the nature and qualities of building materials, with a short exposition of their component parts, would not be misplaced in a treatise of this kind. The Compiler flatters himself, that he has, on this head, furnished some information, that will be serviceable not only to the operator but to the proprietor; neither of whom, can, with safety, remain unacquainted with the quality of the materials employed.

The best writers, on the various subjects treated of in this work, have been consulted, and such use made of their labors, by abridging, altering, abstracting, and condensing, as seemed advisable to the Compiler. While he has added much that has been the result of many years of practical experience and personal observation.

In short, brevity with perspicuity, and utility with cheapness, have been aimed at: how far they have been attained, is submitted to the decision of an enlightened and indulgent public.

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CHAPTER I.

SECTION I.——MARBLE.

THE class of stones denominated *Calcareous*, is exceedingly numerous and abundant in nature. Of these, marble is the most important. It is a granular carbonate of lime, or a compact lime stone, varying in color, texture, and hardness. Its structure is both foliated and granular. The grains are of various sizes, from coarse to very fine, sometimes, indeed, so fine that the mass appears almost compact. When these grains are white, and of a moderate size, this mineral strongly resembles *white sugar* in solid masses.

Its fracture is foliated; but the faces of the laminae, which vary in extent, according to the size of the grains, are sometimes distinguishable only by their glimmering lustre. When the structure is very finely granular, the fracture often becomes a little splintery.

Both its hardness, and the cohesion of its grains, are somewhat variable. In some cases, its hardness undoubtedly depends on the presence of siliceous particles; indeed, it sometimes gives a few sparks with steel. Its specific gravity usually lies between 2. 71, and 2. 84, water being 1.—That is, water as a standard being taken as an unit, the specific gravity of marble is from 2 71-100 units to 2 84-100 units when compared to water, or about 2 3-4 times greater.

It is more or less translucent, but, in the dark colored varieties, at the edges only. Its color is most commonly white or gray, often snow white, and sometimes grayish black. It also presents certain shades of blue, green, red, or yellow. Most frequently the colors are uniform, but sometimes variegated in spots, veins, or clouds, arising from the intermixture of foreign substances.

Marble is essentially *a carbonate of lime*, which is composed of 57 parts of lime, and 43 parts of carbonic acid; a little water is usually present. It is soluble in nitric acid; and by the escape of carbonic acid, more or less effervesence is produced; some varieties, however, effervesce very slowly. Before the blowpipe it decrepitates, and, if pure carbonate of lime, it is perfectly infusible; but, by a strong heat, its carbonic acid is driven off, and quick-lime or pure lime, whose taste is well known, remains.

Marble, in the strict propriety of the term, should be confined to those varieties of carbonate of lime, which are susceptible of a polish; including also some minerals, in which carbonate of lime abounds. But among artists this term is sometimes extended to serpentine, basalt, &c. when polished.

Both granular and compact lime stone furnish numerous varieties of marble; but those, which belong to the *former* exhibit a more uniform color, are generally susceptible of a higher polish, and are hence most esteemed for statuary and some other purposes. The uniformity of color, so common in primitive marbles, is sometimes interrupted by spots, or veins, or clouds, of different colors, arising from the intermixture of hornblende, serpentine, &c. Among the foreign marbles we may mention,

The *Carrara Marble.* Found at Carrara, in Tuscany. It was highly esteemed by the ancients; and is at present more employed by the Italian artist, than any other kind for statuary, vases, slabs for household furniture, &c. It is very white, sometimes veined with gray, and has a grain considerably fine. In the centre of the blocks of this marble very limpid rock crystals are found, which are called Carrara diamonds. The average price of this marble is ten or twelve dollars a cubic foot.

The *Luni Marble.* Found also in Tuscany, is extremely white, and its grain is a little finer, than that of Carrara. Of this marble it is generally supposed, the famous Apollo Belvidere, in the Vatican at Rome, is made, as well as the Antinous of the capitol, and the Antinous in bas-relief in the Napoleon museum.

The *Parian Marble.* Obtained from the islands of Paros, Naxos, &c. in the Archipelago, was much employed by the ancients. It is white, but often with a slight tinge of yellow. Its grains are larger than those of the Carrara marble. The celebrated Venus de Medicis, in the gallery at florence, is of this marble. It was called by the ancients *Lychnites*, in consequence of its quarries being often worked by the light of a lamp. It is on Parian marble that the celebrated tables at Oxford are inscribed.

The *Pentelic Marble.* From mount Penteles, near Athens. This marble much resembles the preceding, but is more dense and fine-grained; it sometimes exhibits faint greenish zones, produced by greenish talc, whence the Italian name *Cipilino statuario.* The principal monuments of Athens were of Pentelic marble, such as the Parthenon, the Propylees, and the Hippodrome. Among the statues of this marble in the Napoleon museum, at Paris, are the Torso; a Bacchus in repose; a Jason, (called Cincinnatus,) a Paris; the Discobolus reposing; the bas-relief, known by the name of the Sacrifice; the throne of Saturn; the Tripod of Apollo; and the two beautiful Athenian inscriptions known by the name of "Nointel Marbles," because M. Nointel caused them to be brought from Athens to Paris in 1672.

Greek White marble. The marble to which the statuaries of Rome give the name of *Marmo Greco*, is of a very bright snow white color, close and fine-grained, and of a hardness, which is rather superior to that of other white marbles. It takes a very fine polish. It has been called corallic marble, from being found near the river Coralus, in Phrigia. According to Pliny, it was found in Asia, in masses of small dimensions; and it is said, that a similar

kind occurs on mount Canuto, near Palermo, in Sicily. The Greek marble was obtained from several islands in the Archipelago; such as Scio, Samos, &c. Among the statues of this marble in the Napoleon museum, are a Bacchus, and Zeno the philosopher.

Translucid White Marble. This much resembles Parian marble, but differs from it as being more translucid. There are, at Venice, and several other towns in Lombardy, columns and altars of this marble, the quarries of which are perfectly unknown.

Flexible White Marble. It is of a beautiful white color, and fine grain. There are five or six tables of it preserved in the house of the prince Borghese, at Rome. They were dug up, as the Abbe Fortis was told, in the field of Mondragone. Being set on end they bend, accillating backward and forward, when laid horizontally, they form a curve.

White Marble of mount Hymettus. This is not a very pure white variety, but inclines a little to gray. Pliny informs us that Lucius Crassus, the orator, was exposed to the sarcasms of Marcus Brutus, because he had adorned his house with six columns, twelve feet high, of the Hymettian marble. The statue of Meleager, in the Napoleon museum, is of this marble.

These are the chief white marbles, which the ancients used for the purposes of Architecture and Sculpture.

Black Antique Marble. (*Nero Antico*, of the Italians.) This differs from the modern black marbles, by the superior intensity of its color. It has been said that the ancients procured this marble from Greece, but it has been ascertained that quarries of real antique black marble have been re-discovered, which were wrought by the ancients, and of which the remains are still to be seen, at the distance of two leagues from Spa, towards Franchimont, not far from Aix-la Chapelle. This marble is extremely scarce, and occurs only in wrought pieces.

Red Antique Marble. (*Rosso Antico*, of the Italians.) This beautiful marble is of a deep blood-red color, here and there with white veins, and if closely examined, is found to be sprinkled over with minute white dots, as if it were strewed sand. Of this kind is the Egyptian Antinous, in the museum at Paris. But the most esteemed variety of Rosso Antico is that of a very deep red, without any veins, such as it is seen in the two antique chairs, and in the bust of an Indian Bacchus in the same museum. The white spots, or points, which are never wanting in the true red antique, distinguish it from others of the same color. It is not known from whence the ancients obtained this marble; the conjecture is that it was brought from Egypt. There is, in the Grimani Palace, at Venice, a colossal statue of Marcus Agrippa, in Rosso Antico, which was formerly preserved in the Pantheon, at Rome.

Green Antique Marble. (*The verde Antico* of the Italians.) This may be considered a kind of Breccia, the paste of which is a mixture of talc and limestone; and the dark green fragments are owing to serpentine more or less pure. The verde antico of the best qual-

ity is that of which the paste is of a grass green, and the blackish spots are of that variety of serpentine, which is called noble serpentine. This marble is much esteemed in commerce, but large pieces of a fine quality are seldom seen. There are four fine columns of it in the Napoleon museum; but much more beautiful ones are preserved at Parma. This verde antico must not be confounded with the marbles known by the names of *vert-de-mer* or *vert-d'-Egypt*. The real verde antico is a breccia, and is never mingled with red spots, while those just mentioned are veined marbles mixed with a dull red substance, which gives them a brownish hue.

Red spotted green Antique Marble. Its ground is very dark green, here and there marked with small red and black spots. The quarries of this marble are lost, and it is found only in small pieces, which are made into tablets, &c.

Leek Marble. (*Marbre poireau* of the French lapidaries.) This is a mixture of limestone and a talcose substance of light green, shaded with blackish green, and related to serpentine. Its texture is filamentose, and as it were ligneous; its fragments are splintery. When polished it exhibits long green veins. Like all other talcose marbles, it soon decomposes in the open air. There is a table of it in the hotel de la Monnoie, at Paris. Its quarries are lost.

Marble petit Antique. Of the French Lapidaries. It is traversed with white and grey veins, the two colors being disposed in uninterrupted threads; the tables made of this marble are irregularly striped their whole length, which has a very fine effect. It is much esteemed, and only made use of for inlaying ornamental furniture. Its quarries are unknown.

Yellow Antique Marble. (*Giallo Antico*, of the Italians.) Of this there are three varieties. The first has more or less the color of the yolk of an egg, and is nearly of an uniform tint; the other is marked with black or deep yellow rings, and the last is merely a paler colored variety of the first. These different marbles, for which the Sienna marble is a good substitute, are found only in small detached pieces, and in antique inlaid work. It is in this manner that the two tables of Lazulite in the Napoleon museum are surrounded with a border of the deep yellow variety.

Grand Antique Marble. This variety, which is a breccia, containing some shells, consist of large fragments of a black marble united by veins or lines of shining white. This superb marble, the quarries of which are lost, is sometimes found in detached pieces and wrought. There are four columns of it in the museum at Paris. A less valuable variety is that in which the spots, instead of being an entire intense black, are of a gray color.

Antique Cipolin Marble. Cipolin is a name given to all such marbles as have greenish zones, caused by green talc; their fracture is granular and shining, and shows here and there plates of tale. They are never found to contain marine bodies. The ancients have made frequent use of Cipolin. It takes a fine polish, but its ribbon-like stripes always remain dull, and are that part of the marble,

which first decompoees, when exposed to the open air. There are modern Cipolins as fine as that used by the ancients.

Purple Antique Breccia Marble. This should not be confounded with African Breccia. There is, perhaps, no marble, the color and spots of which are so variable as that of the violet Breccia. The following are the chief varieties. The first is that from which the name of the marble is derived; it has a purplish brown base, in which are imbedded large angular fragments of a light purple color, and others of a white color. This first variety can be employed only in large works, on account of the size of its spots, which are sometimes a foot in diameter. There is a beautiful table of it in the Napoleon museum. The second variety is, as it were, the miniature of the first; it exhibits the same spots, but within a much narrower compass, so that it may be used for less gigantic works, than those for which the other is employed. The third variety is known in commerce by the name of rose colored marble; in this, the spots, instead of being white and light purple, have a pleasing rose color. It is scarce, and never seen in large pieces. The fourth, which is the most beautiful, appears, at first view, to be perfectly distinct from the others, but it is, nevertheless, a mere variety of the purple breccia. Its ground is of a yellowish green color, and the spots, which are of various sizes, are white, green, purplish and yellow, mottled with red; these various spots are traversed by straight lines of grayish white color. This fourth variety is very scarce. There are, however, two tables of it at Paris, in the possession of private individuals.

African Breccia Marble. Its ground is black, variegated with large fragments of a grayish white, of a deep red, or of purplish wine color; but these latter are always smaller than the former. This is one of the most beautiful marbles existing, and has a superb effect when accompanied by gilt ornaments. Though rather less vivid in its colors than the preceding violet breccia, it is yet, on the whole, more beautiful. Whether Africa is the part of the world where it is found, as its name implies, is not certain. The pedestal of Venus leaving the bath, and a large column, both in the Napoleon museum, are of this marble.

There are other varieties of breccia marble, not differing materially from those already described; they are, many of them, very beautiful, but very scarce, found only in small pieces, among the ruins at Rome.

Marbles are found abundantly, and in variety, in all countries. There are many curious varieties in the United States. The chief quarries that have been noticed are the following:

Stockbridge & Lanesborough Marble. In Berkshire County, Massachusetts. Its grain is somewhat coarse, and its color white, some-

[The term *breccia*, which has often been used in the preceding pages, is applied to an aggregate, composed of angular fragments of the same, or different minerals, united by some cement, sometimes, however, a few of the fragments are a little rounded. The different fragments always present a variety of colors. There are several varieties, some of which are susceptible of a fine polish.]

times with a slight tinge of blue. A quarry has also been opened of a similar kind of marble, at Pittsfield, in the same county.

Vermont Marble. It is found of various qualities, according to Professor Hall, in many places on the west side of the green mountains. A few years since, a valuable quarry was found in Middleburgh, on Otter Creek, eleven miles above Vergennes. The quarry forms one bank of the creek for several roods, and extends back into the side of a hill, to a distance at present unknown. The stone lies in irregular strata, varying considerably in thickness, but all more or less inclined to the north-west. The marble is of different colors in different parts of the bed. On one side, it is of a pure white, and of a quality, if at all, but little inferior to the Italian marble; but this seems to constitute but a small portion of the whole mass. The color that predominates through most parts of the quarry is a gray of different intensities. The marble of both kinds is solid, compact, free from veins of quartz, and susceptible of an excellent polish. A mill of peculiar construction has been erected for the purpose of sawing the stone into slabs. It contains sixty five saws, which are kept almost in continual operation. During the years of 1809 and 1810 these saws cut out 20,000 feet of slabs, and the sales of marble tables, side-boards, tomb-stones, &c. in the same period, amounted to about 11,000 dollars.

Some of the Vermont marbles are as white as the Carrara marble, with a grain intermediate between that of the Carrara and Parian marbles.

New Haven Marble. The texture of this very beautiful marble is granular, but very fine. Its predominant colors are gray and blue, richly variegated by veins or clouds of white, black, or green; indeed, the green often pervades a large mass. It takes a high polish, and endures the action of fire remarkably well. This marble contains chromate of iron, magnetic oxide of iron, and *serpentine*; hence it resembles the *vert antique*, and is, perhaps, the only marble of the kind hitherto discovered in America.

Thomastown Marble. From Lincoln County, Maine. It is, in general, fine-grained, and its colors are often richly variegated. Sometimes it is white, or grayish-white, diversified with veins of a different color. But, in the finest pieces, the predominant color is gray, or bluish-gray, interrupted with whitish clouds, which, at a small distance, resemble the minutely shaded parts of an engraving, and, at the same time, traversed by innumerable small and irregular veins of black and white. It recieves a fine polish, and is well fitted for ornamental works.

Some of the white marble of Vermont, and that which may be obtained at Smithfield, in Rhode-Island, more peculiarly deserve the name of *statuary* marble.

Flexible Marble, has been observed at Pittsford, Rutland county, Vermont; and at Pittsfield in Massachusetts.

Pennsylvania Marble. There is found at Aaronsburg, in Northumberland county, a black marble. It is of compact limestone, containing white specks. At Marbletown, near the Hudson river, in the state of New-York, is a quarry of very fine black marble, spot-

led with white shells. Marble has also been found in Virginia, and some other of the United States. But the state of the arts has not, hitherto, directed the attention of the curious so much to this subject as it intrinsically deserves.

SECTION II.——The Polishing of Marble.

The art of cutting and polishing marble was, of course, known to the ancients, whose mode of proceeding appears to have been nearly the same with that employed at present; except, perhaps, that they were unacquainted with those superior mechanical means, which now greatly facilitate the labor, and diminish the expense of the articles thus produced. There are many manufactories of this kind, generally called marble mills, on the continent, and also in Great Britain; but as the principle on which they proceed is nearly the same in all, it will suffice in this place to give the description of one or two of the latter.

An essential part of the art of polishing marble is the choice of substances by which the prominent parts are to be removed. The first substance should be the sharpest sand, so as to cut as fast as possible, and this is to be used till the surface becomes perfectly flat. After this, the surface is rubbed with a finer sand, and frequently with a third. The next substance, after the finest sand, is emery of different degrees of fineness. This is followed by the red powder called tripoli, which owes its cutting quality to the oxide of iron it contains. Common iron-stone, powdered and levigated, answers the purpose very well. This last substance gives a tolerably fine polish. This, however, is not deemed sufficient. The last polish is given with putty. After the first process, which merely takes away the inequalities of the surface, the sand employed in preparing it for the emery should be chosen of an uniform quality. If it abounds with some particles harder than the rest, the surface will be liable to be scratched so deep as not to be removed by the emery. In order to get the sand of uniform quality, it should be levigated and washed. The hard particles being generally of a different specific gravity to the rest, may, by this means, be separated. This method will be found much superior to that of sifting. The substance by which the sand is rubbed upon the marble is generally an iron plate, especially for the first process. A plate of an alloy of lead and tin is better for the succeeding processes, with the fine sand and emery. The rubbers used for the polishing, or last process, consist of coarse linen cloths, such as hop bagging, wedged tight into an iron plane. In all of these processes, a constant supply of water, in small quantities, is absolutely necessary.

The sawing of marble is performed on the same principles as the first process of polishing. The saw is of soft iron, and is continually supplied with water and the sharpest sand.

Marble is extensively used for building, statuary, decorations and inscriptions. In warm countries it is one of the most durable of

substances, as is proved by the edifices of Athens, which have retained their polish for more than two thousand years. Severe frost, preceded by moisture, causes it to crack and scale, great heat reduces it to quick-lime. It may be burnt, like other varieties of lime-stone, into lime for preparing mortar, or employed as a flux for certain ores, particularly those which contain alumine and silex.

White marble is sometimes cleaned by muriatic acid diluted with water. Spots of oil stain white marble, so that they cannot be taken out.

SECTION III.——Artificial Marble.

The stucco, whereof they make statues, busts, basso relievos, and other ornaments of architecture, ought to be marble pulverized, mixed in a certain proportion with plaster; The whole well sifted, worked up with water, and used like common plaster. [*See Stucco.*]

There is also a kind of artificial marble, made of flake selenites, or a transparent stone resembling the plaster; which becomes very hard and receives a tolerable polish, and may deceive the eye. This kind of selenites resembles Muscovy talc. There is another sort of artificial marble, formed by corrosive tincture, which, penetrating into white marble, to the depth of a line or more, imitates the various colors of other dearer marbles. There is also a preparation of brimstone in imitation of marble. To do this, you must provide yourself with a flat and smooth piece of marble. On this make a border or wall, to encompass either a square or oval table, which may be done either with wax or clay. Then, having provided several sorts of colors, as white-lead, vermillion, lake, orpiment, masticot, Prussian-blue, &c. melt, on a slow fire, some brimstone, in several glazed pitkins; put one particular sort of color into each, and stir it well together; then having before oiled the marble all over within the wall, with one color quickly drop spots upon it of larger and less size; after this take another color, and do as before; and so on, till the stone is covered with spots of all the colors you design to use. When this is done, you are next to consider what color the mass, or ground of your table is to be; if of a grey color, then take fine sifted ashes, and mix them up with melted brimstone, or if red, with English red ochre; if white, with white lead; if black, with lamp or ivory black. Your brimstone for the ground must be pretty hot, that the colored drops on the stone may unite and incorporate with it. When the ground is poured even all over, you are next, if judged necessary, to put a thin wainscot board upon it; this must be done while the brimstone is hot, making also the board hot, which ought to be thoroughly dry, in order to cause the brimstone to stick the better to it. When the whole is cold, take it up, and polish it with a cloth and oil, and it will look very beautiful.

SECTION IV.——The Coloring of Marble.

The coloring of marble is a nice art, and in order to succeed in it, the pieces of marble, on which the experiments are tried, must be well polished, and clear from the least spot or vein. The harder the marble is, the better it will be, and the greater the heat necessary in the operation; therefore, alabaster, and the common soft white marble are very improper to perform these operations upon.

Heat is always necessary, for the opening of the pores, so as to render it fit to receive the colors; but the marble must never be made red hot, for then the texture of the marble itself is injured and the colors are burnt, and lose their beauty. Too small a degree of heat is as bad as too great; for, in this case, though the marble receives the color, it will not be fixed in it, nor strike deep enough. Some colors will strike even cold; but they are never so well sunk in as when a just degree of heat is used. The proper degree is that, which, without making the marble red, will make the liquor boil on its surface. The menstruums used to strike in the colors, must be varied according to the nature of the color to be used. A lixivium made of horses or dog's urine, with four parts of quick lime, and one part pot-ashes, is excellent for some colors; common ley, of wood ashes, does very well for others; for some, spirit of wine is best, and finally, for others, oily liquors, or common white wine.

The colors which have been found to succeed best with the peculiar menstruums, are these: stone-blue dissolved in six times the quantity of spirit of wine, or of the urinous lixivium, and that color, which the painters call litmus, dissolved in common ley, of wood ashes. An extract of saffron, and that color made of buckthorn berries, and called by the painters soap-green, both succeed, well dissolved in urine and quick-lime, and tolerably well in spirit of wine. Vermilion, and a fine powder of cochineal, succeed also very well in the same liquors. Dragon's blood succeeds very well in spirit of wine, as does also a tincture of logwood in the same spirit. Alkanet root gives a fine color, but the only menstruum to be used for this is oil of turpentine; for neither spirit of wine, nor any lixivium will do with it. There is a kind of substance, called dragon's blood in tears, which, mixed with urine alone, gives a very elegant color.

Besides these mixtures of colors, and menstruums, there are some colors, which are to be laid on dry and unmixed. These are dragon's blood of the purest kind, for a red; gamboge, for a yellow; green wax, for a green; common brimstone, pitch and turpentine, for a brown color. The marble, for these experiments, must be made considerably hot, and the colors are to be rubbed on dry, in the lump. Some of these colors, when once given, remain immutable; others are easily changed or destroyed. Thus the red color, given by dragon's blood, or by the decoction of logwood, will be

wholly taken away by oil of tartar, and the polish of the marble not hurt by it.

A fine gold color is given in the following manner: take crude sal-ammoniac, vitriol, and verdigris, of each, equal quantities; white vitriol succeeds best, and all must be thoroughly mixed in fine powder.

The staining of marble, to all degrees of red, or yellow, by solution of dragon's blood or gamboge, may be done by reducing these gums to powder, and grinding them with the spirit of wine, in a glass mortar; but for smaller attempts, no method is so good as the mixing a little of either of these powders with spirit of wine, in a silver spoon, and holding it over burning charcoal. By this means, a fine tincture will be extracted, and with a pencil dipped in this, the finest traces may be made on the marble, while cold, which, on heating of it afterwards, either on sand, or in a baker's oven, will all sink very deep, and remain perfectly distinct in the stone. It is very easy to make the ground color of the marble red or yellow, by this means, and leave white veins in it. This is to be done by covering the places where the whiteness is to remain with some white paint, or even with two or three doubles only of paper, either of which will prevent the color from penetrating in that part. All the degrees of red are to be given to the marble by the means of this gum alone; a slight tincture of it, without the assistance of heat to the marble, gives only a pale flesh color; but the stronger tinctures give it yet deeper. To this the assistance of heat adds yet greatly; and finally, the addition of a little pitch, to the tincture, gives it a tendency to blackness, or any degree of deep red that is desired.

A blue color may be given to marble, by dissolving turnsol in a lixivium of lime and urine, or in the volatile spirit of urine; but this has always a tendency to purple, whether made by one or the other of these ways. A better blue, and used in an easier manner, is furnished by the Canary turnsol, a substance well known among the dyers. This need only be dissolved in water, and drawn on the place with a pencil; this penetrates very deep into the marble, and the color may be increased by drawing the pencil, wetted afresh, several times over the same lines. This color is subject to spread and diffuse itself irregularly; but it may be kept in regular bounds, by circumscribing its lines with beds of wax, or any other substance. It is to be observed, that this color should always be laid on cold, and no heat given ever afterwards to the marble; and one great advantage of this color is, that it is easily added to marbles already stained with any other colors, and it is a very beautiful tinge, and lasts a long time.

This art has, in several persons' hands, been a very lucrative secret, though there is scarcely anything in it, that has not, at one time or another, been published.

Kircher has the honor of being one of the first who published anything practicable about it. This author meeting with stones in some cabinets, supposed to be natural, but having figures too nice and particular to be supposed to be nature's making, and these not only on the surface, but sunk through the whole body of the stones,

was at the pains of finding out the artist, who did the business; and on his refusing to part with the secret on any terms, this author, with Albert Gunter, a Saxon, endeavored to find it out. Their method is this. Take aqua fortis and aqua regia, of each one ounce, sal-ammoniac one ounce, spirit of wine two drachms, about twenty-six grains of gold, and two drachms of pure silver; let the silver be calcined and put into a phial, and pour upon it the aqua fortis; let this stand some time, then evaporate it, and the remainder will at first appear of a blue, and afterwards of a black color; then put the gold into another phial, and pour the aqua regia upon it, and when it is dissolved, evaporate it as the former; then put the spirit of wine upon the sal-ammoniac, and let it be evaporated in the same manner. All the remainders, and many others made in the same manner from other metals, dissolved in their proper acid menstrua, are to be kept separate, and used with a pencil on the marble: These will penetrate without the least assistance of heat, and the figure being traced with a pencil on the marble, the several parts are to be touched over with the proper colors, and this renewed daily, till the colors have penetrated to the desired depth into the stone.

After this, the mass may be cut into thin plates, and every one of them will have the figure exactly represented on both surfaces, the colors never spreading.

The nicest method of applying these, or the other tinging substances, to marble that is to be wrought into any ornamental works, and where the back is not exposed to view, is to apply the colors behind, and renew them often, till the figure is sufficiently seen through the surface on the front, though it does not quite extend to it. This is the method, that, of all others, brings the stone to a nearer resemblance of natural veins of this kind. The same author gives another method to color marble, by vitriol, bitumen, &c. forming a design of what you like upon paper, and laying the said design between two pieces of polished marble; then closing all the interstices with wax, you bury them for a month or two in a damp place. On taking them up, you will find that the design you painted on the paper has penetrated the marbles, and formed exactly the same design upon them.

SECTION V.——GRANITE.

GRANITE is apparently the oldest and deepest of rocks. It is one of the hardest and most durable which have been wrought, and is obtained in larger pieces than any other rock. Granite is a compound stone, varying in color and coarseness. It consists of three constituent parts, united to each other without the intervention of any cement, viz. *quartz*, the material of rock crystal; *feldspar*, which gives it its color; and lastly *mica*, a transparent, thin, or foliated substance.

But in order to understand more perfectly the nature and qualities of granite, some examination of its constituent parts is necessary.

I. QUARTZ belongs to that class of minerals, denominated *earthy compounds*, or *stones*. It embraces numerous varieties, differing much in their forms, texture, and other external characters. And although but few well defined external characters apply to the whole species, yet most of its varieties are easily recognized.

It is sufficiently hard to scratch glass, and it always gives sparks with steel. When pure, its specific gravity is about 2. 63. water being 1.; but in certain varieties extends above and below this term, depending on its structure, or the presence of foreign ingredients. Indeed, the mean specific gravity of the whole species, is about 2. 60. It is sometimes in amorphous masses, and sometimes in very beautiful crystals, of which the primitive form is a rhomb slightly obtuse, the angles of its faces being 94° 24′ and 85° 36′.— The secondary form, the most common, is a six-sided prism, terminated by six-sided pyramids. It exhibits double refraction, which must be observed by viewing an object through one face of the pyramid and the opposite side of the prism. Its fracture is vitreous.

(*Chemical Characters.*) All the varieties of quartz are infusible by the blow-pipe, and if pure, it is scarcely softened, even when the flame is excited by oxygen gas. Before the compound blow-pipe, a fragment of rock chrystal instantly melts into a white glass.— Quartz is essentially composed of silex or the principal ingredient of flint, from 93 to 98 parts being of this substance, and the residue alumine, lime, water, or some metallic oxide.

Among the varieties, are 1. the *Limpid Quartz*, (Rock Crystal,)— This, the most perfect variety of Quartz, has, when crystalized, received the name of *rock crystal*; indeed the same name is sometimes extended to colored crystals, when transparent. Limpid quartz is without color, and sometimes as transparent as the most perfect glass, which it strongly resembles. It is, however, harder than glass, and the flaws or bubbles, which it often contains, lie in the same plane, while those in glass are irregularly scattered. The finest crystals are found in veins, or cavities, in primitive rocks, as in granite, gneiss or mica slate, or in alluvial earths.

In the *United States* this variety is not uncommon. It is found in *Virginia*, near the North Mountain. In Frederick Co. *Maryland*, crystals are scattered on the surface of the ground, of perfect transparency, with a splendent lustre. In *New-York*, on an island in Lake George, are very fine crystals—and in *Vermont*, at Grafton. This variety is sometimes employed in Jewelry, for watch seals, &c.

2. *Smoky Quartz.* Objects seen through this variety, seem to be viewed through a cloud of *smoke*. Its true color seems to be clove brown. It is sometimes called *smoky* topaz.

3. *Yellow Quartz.* Its color is pale yellow, sometimes honey or straw yellow. It has been called *citrine*; and also *false*, or *Bohemian* topaz.

4. *Blue Quartz.* Its color is blue, or grayish blue. It is inferior in hardness to the former varieties.

5. *Rose Red Quartz.* Its color is rose red of different shades, sometimes with a tinge of yellow. It is seldom more than semi-

transparent. Its color, which is supposed to arise from manganese, is said to be injured by exposure to light. It has been called *Bohemian* ruby. It is sometimes employed in jewelry, and much esteemed.

6. *Irised Quartz.* It reflects a series of colors, similar to those of the iris or rainbow.

7. *Aventurine Quartz.* Its predominant color, which may be red, yellow, gray, greenish, blackish, or even white, is variegated by brilliant points, which shine with silver or golden lustre. It is sometimes employed in ornaments of jewelry.

8. *Milky Quartz.* Its color is milk white, in some cases a little bluish ; and it is nearly opaque. Its fracture has sometimes a resinous lustre. It is sometimes in small crystals, but more often in large masses.

9. *Greasy Quartz.* Its colors are various, either light or dark. Its fracture appears as if rubbed with oil.

10. *Radiated Quartz.* It is in masses which have a crystalline structure, and are composed of imperfect prisms. These prisms usually diverge a little, or radiate from the centre, and often separate with great ease.

11. *Tabular Quartz.* It occurs in plates of various sizes, which are sometimes applied to each other by the broader faces.

12. *Granular Quartz.* Its structure presents small granular concretions, or grains, which are sometimes feebly united. This variety must be carefully distinguished from certain sand-stones which it resembles. It may be important—in the manufacture of glass, and certain kinds of stone-ware.

13. *Arenaceous Quartz.* It is in loose grains, coarse or fine, either angular or rounded, and constitutes some varieties of pure sand.—Certain sand-stones appear to be composed of this quartz, united by some cement.

14. *Pseudomorphous Quartz.* It appears under regular forms, such as cubes, octædrons, &c. which do not belong to the species. They are opaque, their surfaces dull, and their edges often blunted.

Common quartz never forms whole mountains. It is sometimes in large masses, or in beds, and frequently, in extremely large veins, which have been mistaken for beds. Quartz, in the form of crystalized grains, or of irregular masses of various sizes, is abundantly disseminated in granite, gneiss, mica slate, &c. of all which it forms a constituent part. It is sometimes in regular crystals, dispersed through the granite. In porphyry, also, it is sometimes regularly crystalized. It also occurs in carbonate of lime, anthracite, &c.—Among secondary rocks, quartz is found forming a greater part of many sand-stones ; also between strata of compact limestone, of clay, or of marl, or imbedded in sulphate of lime.

In alluvial earths it exists in the form of sand. Quartz is often associated with the carbonate and fluate of lime, sulphate of barytes, and feldspar, in metallic veins ; indeed, it exists in almost every metallic vein.

Hornblend, schorl, epidote, garnet, magnetic-iron, are also among the minerals contained in quartz. Mica gives it a slaty structure.

In some rare instances, bubbles of air, and even drops of water, and bitumen, have been found in quartz. Although common quartz never contains any organic remains, it is sometimes crystalized in fossil wood.

Quartz is found very abundantly in most of the northern and middle states.

We have already seen that certain varieties of quartz are employed in Jewelry. It is also used, especially the sandy variety, in the manufacture of glass ; also in the preparation of smalt and certain enamels.

II. Feldspar. This important and widely distributed mineral, has, in most of its varieties, a structure very distinctly foliated. It scratches glass, and gives sparks with steel, but its hardness is a little inferior to that of quartz. When in crystals or crystaline masses, it is very susceptible of mechanical division, at natural joints, which, in two directions perpendicular to each other, are extremely, perfect ; but in the third direction, they are usually indistinct.

The primitive form, thus obtained, is an oblique, angled parallelogram, whose sides are inclined to each other in angles of 90° 120° and 111° 28′. The four sides, produced by the two divisions, perpendicular to each other, have a brilliant polish, while the two other sides are dull ; this is a distinctive character of great importance. Its specific gravity usually lies between 2. 43 and 2. 70.— It possesses double refraction, which, however, is not easily observed. It is usually phosphorescent, by friction, in the dark.

(*Chemical Characters.*) Before the blow-pipe it melts into a white enamel or glass, more or less translucent. The results of analysis have not yet been perfectly satisfactory in regard to the true composition of feldspar. It appears probable, however, that not only silex and alumine, but also lime and potash are essential ingredients. In a specimen of green feldspar Vauquebin found 62. 83 parts of silex, 17. 02 of alumine, 13. 0 of potash, 3. 0 of lime, and 1. 0 of oxide of iron = 96. 85 in an 100 parts.

Several of the varieties of Feldspar deserve notice.

1. *Common Feldspar.* This variety occurs in fragments often rolled, also in grains in sand, but more commonly in masses of moderate size, forming an ingredient of compound minerals. It is not unfrequently in regular crystals, of the primitive form, already mentioned.

The crystals of feldspar, seldom very small, are sometimes *several inches* both in diameter and length ; their faces are shining, and their edges sometimes very perfect. Their prevailing form is an oblique prism, whose sides are unequal, and vary in number, from four to ten. The terminating faces, of which two are commonly longer than the others, are subject to great variation in number and extent ; indeed, they often seem to have no symmetry in their arrangement, a circumstance which arises from the obliquity and irregularity of the primitive form.

The longitudinal fracture is foliated, and its lustre more or less shining and vitreous, sometimes pearly, especially in certain spots; the cross fracture is uneven or splintery, and nearly dull. It is easily broken, and falls into rhomboidal fragments, which have four polished faces. The folia are sometimes curved, or arranged like the petals of a flower.

It is more or less translucent, sometimes nearly, or quite opaque, and presents a great variety of colors. Among these are white, tinged with gray, yellow, green or red; gray, often with a shade of blue; several shades of red, as flesh or blood red; to which must be added green, yellow, brown, or even black.

This variety is abundant, and constitutes an essential ingredient of granite, gneiss, sienite, and green-stone. Of granite and sienite it sometimes forms two thirds of the whole mass. It exists also in argillite and porphyry &c. Its crystals, though sometimes imbedded, are more often found in the fissures or cavities of these rocks, and are sometimes associated with epidote, axinite, chronite, amianthus, carbonate of lime, quartz, magnetic oxide of iron &c.

2. *Green Feldspar.* The variety is rare, and has an apple-green color, varying somewhat in intensity, and sometimes marked with whitish stripes.

3. *Adularia.* This is the most perfect variety of feldspar, and bears to common feldspar, in many respects, the relation of rock crystal to common quartz. It is more or less translucent, and sometime transparent and limpid. Its color is white, either a little milky, or with a tinge of green, yellow, or red. But it is chiefly distinguished by presenting, when in certain positions, whitish reflections, which are often slightly tinged with blue or green, and exhibit a pearly or silver lustre. Adularia is sometimes cut into plates and polished. The *fish's eye moon-stone*, and *argentine* of lapidaries come chiefly from Persia, Arabia, and Ceylon, and belong to Adularia, as do also the *water-opal* and *girasole* of the Italians.

4. *Opalescent Feldspar.* This very beautiful variety is distinguished by its property of reflecting light of different colors, which appear to proceed from its interior. Its proper color is gray, often dark or blackish gray, and sometimes specimens are marked with whitish spots or veins. But when held in certain positions it reflects a very lively and beautiful play of colors, embracing almost every shade of green and blue, and several shades of yellow, red, gray, and brown. These colors are usually confined to certain spots, and even the same spot changes its color in different positions. It is much esteemed in jewelry.

5. *Aventurine Feldspar.* Its colors are various; but it contains little spangles or points, which reflect a brilliant light.

6. *Petuntze.* It is nearly, or quite opaque, and its color is usually whitish or gray. It has, in most cases, less lustre than common feldspar. It most usually occurs in beds. Its powder is said to have a slightly saline taste. It is used in the manufacture of porcelain, both for an enamel, and its composition.

7. *Granular Feldspar.* It is nearly, or quite opaque, and imperfectly foliated. It varies much in hardness, and is sometimes friable between the fingers. Its color is usually white, and sometimes strongly resembles masses of white sugar. Feldspar is found in the northern, and most of the middle states.

III. MICA. Mica appears to be always the result of crystalization, but it is rarely found in regular, well defined crystals. Most commonly it appears in thin, flexible, elastic laminae, which exhibit a high polish and strong lustre. These laminae have sometimes an extent of many square inches; and from this, gradually diminish, till they become mere spangles. They are usually found united into small masses, extremely variable in thickness, or into crystals more or less regular; their union, however, is so very feeble, that they are easily separable, and may be reduced to a surprising degree of tenuity. In this state their surface becomes irised, and their thickness does not exceed a millionth part of an inch.

The crystals of mica are sometimes right prisms with rhombic bases, whose angles are 120° and 62°. This is also the primitive form, in which one side of the base is, to the height of the prism, nearly as 3 to 8.

The structure of Mica is always foliated, but the foliae may be straight, curved or undulated. The surface has a shining or splendent lustre, which is usually metallic, sometimes like that of silver or gold; and sometimes like that of polished glass. It is easily scratched by a knife, and in most cases, even by the finger nail. Its surface is smooth to the touch, and *very seldom* slightly unctuous; its powder is dull, grayish, and feels soft. It is often transparent, in other cases it is only translucent, sometimes at the edges only. Its colors are silver white, grey, often tinged with yellow, green, or black; also brown, reddish, and green.

Its specific gravity extends from 2.53 to 2.93; and when rubbed on sealing wax, it communicates to the wax negative electricity.

(*Chemical Characters.*) It is fusible by the blow-pipe, though sometimes with difficulty, into enamel, which is usually gray or black. The colored varieties are the most easily fusible; and black mica gives a black enamel, which often moves the needle. It contains, according to Klaproth, silex 48.0, alumine 34.25, potash 8.75, oxide of iron, 4.5, oxide of manganese 0.5 ;=96. Sometimes the potash is in greater proportion, and in black mica the oxide of iron is sometimes as high as 22 per cent. Mica is subject to decomposition by exposure to the atmosphere.

The following are the most important varieties of mica.

1. *Laminated Mica.* It occurs in large plates, which often contain many square inches. It has been called *Muscovy* glass, or talc, being found abundantly in that country.

2. *Lamellar Mica.* This is the more common variety. It exists in small foliae, either collected into masses, or disseminated in other minerals. It is sometimes in extremely minute scales, which, when detached from the mass, appear like sand.

3. *Prismatic Mica.* This variety is not common. The laminae are easily divisible, parallel to their edges, into minute prisms, or even into delicate filaments. The edges of the laminae have usually more lustre than those of the other varieties.

Although mica never occurs in beds, or large insulated masses, there is no substance more universally diffused through the mineral kingdom. It is an essential ingredient in granite, gneiss, and mica-slate; and occurs also in sienite, porphyry, and other primitive rocks. Mica occurs also in green-stone, basalt, sand-stone, and other secondary rocks; especially in sand-stone and shell, which accompany coal,

In the United States mica is very abundant.

It has been employed instead of glass, in the windows of dwelling houses; also in ships of war, because it is not liable to be broken by the concussion produced by the discharge of cannon. In lanterns it is superior to horn, being more transparent, and not so easily injured by heat. When in thin transparent laminae, sufficiently large, it is useful to defend the eyes of those who travel against high winds and severe storms of snow. When of suitable color and in minute scales, it is employed to ornament paper, which is then said to be *frosted;* the scales of mica are made to adhere by a solution of gum or glue.

These are the ingredients, of which granite is composed.

The structure of granite is granular; but the grains are extremely variable both in size and form. Most frequently the size of the grains lies between that of a pin's head and a nut. Sometimes, however, they are several inches, and even more than a foot, in their dimensions, and sometimes they are so minute, that the mass resembles a sand-stone, or even appears almost homogeneous to the naked eye.

The forms of these grains are, in general, altogether irregular, like those of the fragments of most minerals. In some granites the feldspar or quartz, or even the mica, is in crystals more or less regular.

The ingredients of granite vary much in their proportions; but in general, the feldspar is most abundant, and the mica is usually in the smallest proportion. Their arrangement is also various; sometimes, while the feldspar and quartz are mingled with considerable uniformity, the mica appears only in scattered masses, or is found investing grains of feldspar and quartz on all sides. In other cases the feldspar and mica, or quarts and mica are mingled, while the third ingredient appears in small distinct masses.

One of the ingredients of this rock, most frequently the quartz or mica, may be entirely wanting, through a greater or less portion of the mass, so that specimens of true granite, (*as it is sometimes called*) contain only two ingredients.

The predominant color of granite usually depends on that of the feldspar, which may be white or grey, sometimes with a shade of red, yellow, blue, or green, and sometimes it is flesh red. The quartz may be white, grayish-white, or grey, sometimes very dark; but it is usually vitreous and translucent. The mica may be black, brown, grey, silver, white, yellowish or violet.

The simple minerals, which enter into the composition of granite, are, in general, so intimately united, that the mass is firm and solid; but some varieties are brittle, and easily become disintegrated. The feldspar sometimes undergoes a partial decomposition, losing its lustre, hardness, and foliated structure, while, at other times, it is converted into porcelain clay. The mica also, when exposed to the open air, is subject to alteration, or even decomposition. Sulphuric acid is often generated by the decomposition of the Sulphuret of iron, disseminated in the granite, and this acid acts upon the mica in its vicinity, thus producing a soft substance, and diminishing the firmness of the granite. Granite, which embraces schorl, is also liable to disintegration.

The specific gravity of granite general lies between 2. 5 and 2. 6, but is sometimes higher.

Among the varieties of granite are,

1. *Graphic Granite.* This very beautiful variety of granite is composed chiefly of feldspar and quartz. The feldspar is very abundant, forming a base, in which quartz, under various forms, lies imbedded. When this granite is broken in a direction, perpendicular to that in which the quartz traverses the feldspar, the surface of the fracture ordinarily presents the general aspect of *letters*, arranged in parallel lines; and hence its name. These letters of grey, vitreous quartz, on a shining and polished tablet of white, or flesh colored feldspar, appear extremely beautiful. It is principally this variety of granite, which, by its decomposition, furnishes porcelain clay.

2. *Globular Granite.* This is composed of large, globular, distinct concretions, which are sometimes several feet in diameter. These concretions are united by a kind of granite, which is readily disintegrated, thus leaving the globular masses detached from each other.

3. *Porphyritic Granite.* This variety is produced, when large crystals of feldspar are interspersed in a fine-grained granite.

Granite is always a primitive rock; and never embraces any organic remains of animals or vegetables.

It exists very extensively, and in many countries it occurs in immense quantities. It constitutes a large portion of many of the highest mountains, of which it appears to form the central parts, as well as the summits. It is more or less abundant in the mountains of Scotland and Germany; the Alps, the Carpathean, the Uralian, and the Altian mountains; the Andes, and the United States.

Granite is chiefly used as a building stone. It is split from the quarries by rows of iron wedges, driven simultaneously in the direction of the intended fissure. This method is thought by Brard to have been known to the ancient Romans and Egyptians. The blocks are afterwards hewn to a plane surface, by the strokes of a sharp-edged hammer. Granite is also chisseled into capitals and decorative objects, but this operation is difficult, owing to its hardness and brittleness. It is polished by long-continued friction, with sand and emery.

The largest mass of granite, known to have been transported in modern times, is the pedestal of the equestrian statue of Peter the Great, at St. Petersburg. It is computed to weigh three millions pounds, and was transported nine leagues, by rolling it on cannon balls: those of iron being crushed, others of bronze were substituted. Sixty granite columns at St. Petersburg, consist each of a single stone, twenty feet high. The columns in the portico of the Pantheon at Rome, which are thirty-six feet, eight inches high, are also of granite. The shaft of Pompey's Pillar, in Egypt, is sixty-three feet in height, and of a single piece. It is said to be of red granite, but is possibly sienite. In the Eastern part of the United States, a beautiful white granite is found in various places, and is now introduced into building. The new Market-House in Boston, the United States Bank, the Tremont House and Theatre, &c. are made of it.

SECTION VI.——SIENITE.

This rock is related to Granite, and resembles it in its general characters. *Feldspar* and *hornblend* may be considered its constant and essential ingredients. Feldspar is the most abundant ingredient, and has already been described, (*see granite*) but as it is, however, the presence of hornblend, as a constituent part, which distinguishes this rock from granite, some account of it may be useful.

I. HORNBLEND is a very common mineral, and may, in general, be easily recognized. Sometimes it is in regular and distinct crystals, but more commonly it appears in masses, composed of laminae, or fibres, variously aggregated, the result of confused crystallization.

When its structure is sufficiently regular, mechanical division is easily effected in a longitudinal direction; and its crystals are found to be composed of laminae, situated parallel to the sides of an oblique four-sided prism, with rhombic bases; the sides of this prism are inclined to each other, at angles of 124° 34′ and 55° 26′. The longitudinal fracture is of course foliated, and usually presents the broken edges of many laminae extending one beyond another.

Hornblend usually scratches glass, and sometimes with difficulty gives sparks with steel. Its powder is dry, and not soft to the touch. It is often opaque, sometimes translucent. It is generally black and green, often intermixed. Its specific gravity is about 3. 20.

(*Chemical Characters.*) Before the blow-pipe it melts with considerable ease, and forms black, or greyish black glass, or greyish enamel. It yields, by analysis, silex, alumine, magnesia, and lime, but in variable proportions. Its colors are produced by the oxides of iron and of chrome.

Masses of hornblend, whether fibrous, lamellar, or nearly compact, possess a remarkable tenacity, which renders them tough and difficult to break; indeed, a considerable cavity may often be produced by the hammer, before the mass breaks. They exhale when moistened by the breath, a peculiar argillaceous odor.

Some of the varieties are,

1. *Basaltic Hornblend*, which is found in lava and volcanic scoriae, and very often in *Basalt;* and hence its name. It is almost always in distinct crystals, whose color is a pure black, sometimes slightly tinged with green, or brownish, by decomposition. Their surface is sometimes strongly shining, at other times dull, and invested with a feruginous crust. Its structure is more foliated, than that of other varieties, and its crystals more brittle.

2. *Lamellar Hornblend*. Its masses are sometimes composed merely of lamellar, and sometimes of granular concretions of various sizes, having a lamellated structure. Hence the fracture is foliated, but the foliae are variously inclined and interlaced.

3. *Fibrous Hornblend*. It occurs in masses, composed of acicular crystals or fibres, either broad or narrow, parallel or interlaced.

4. *Slaty Hornblend* or *Hornblend Slate*. This variety scarcely differs from the preceding, except in the slaty structure of its masses. For each individual layer is composed of very minute fibres, diverging in bundles, or promiscuously, and often interlaced.

Hornblend is an essential ingredient in sienite and green-stone, as well as in basalt and lava.

Sienite, being composed of these two ingredients, is usually granular; but the grains are sometimes coarse, and sometimes very fine. In some instances its structure is slaty. When this rock is very fine grained, and, at the same time, contains large crystals of feldspar, it constitutes *sienetic porphyry*.

The feldspar, whose foliated texture is often very distinct, is most frequently reddish or whitish; but sometimes it receives a greenish tinge, from the hornblend, or from epidote.

Sienite is sometimes found resting on granite, gneiss, mica-slate, or argillite, and sometimes it is associated with green-stone and argillaceous porphyries.

This rock is often altered at the surface by the action of the weather, more especially in those varieties, which contain an uncommon proportion of feldspar. It often is susceptible of a good polish; and may be employed for the same purposes as porphyry. Its name is derived from that of Sienna, a city in Egypt, where it is found in abundance, and constitutes the material of many of the obelisks. The Romans imported it for purposes of statuary and architecture.

Sienite is obtained in large pieces, and possesses all the valuable qualities of granite, as a building stone. It is somewhat harder than granite, and more difficult to chissel. It is found abundantly, near Boston, at Weymouth, Brighton, Quincy, &c. and is introduced into many structures. The Washington Bank, and the Bunker Hill

monument consist of this stone. It is rendered, by its extreme hardness, one of the best materials for M'Adamising roads. The railway at Quincy, is built for transporting this stone from the quarry to the sea, and it is there commonly called the *Quincy stone*.

SECTION VII.——Green-Stone.

Sienite and green-stone are essentially composed of the same ingredients, namely, *feldspar* and *hornblend*. And the two rocks do, in fact, pass into each other by insensible shades. *But in greenstone, the hornblend predominates, while, in sienite, the feldspar is the most abundant ingredient.* This frequently gives to this stone, more or less of a *greenish* tinge, especially when it is moistened; hence the name of this rock. Sometimes the tinge of green is considerable lively; sometimes, also, its color is a dark gray, or grayish black. In short, its color, especially at the surface, is often modified by the presence of oxide of iron.

It presents a considerable diversity of aspect, depending on the general structure, or on the size, proportion, disposition, and more or less intimate mixture of its constituent parts. From green-stone, with a coarse granular structure, to those varieties whose texture is so finely granular that the two ingredients can scarcely be perceived, there is a gradual passage, exhibiting every intermediate step. Indeed, the grains are sometimes so minute, and so uniformly and intimately mingled, that the mass appears altogether homogeneous, and the different ingredients are hardly perceptible—even with a glass.

It sometimes presents *prisms* or *columns* of various size. These prisms may have from three to seven sides, and are often quite regular. Many green-stones are susceptible of a polish. It occurs in beds, more or less large, and sometimes forms whole mountains.

Green-stone is common in the United States. When this rock breaks into prismatic fragments, it forms a very useful building stone. Most of its varieties, when heated red hot, plunged into cold water, and pulverized, become a good substitute for puzzolana in preparing water-proof mortar for the construction of walls, cellars, docks, piers, &c. This rock has sometimes received the appellation of *Trap*, which seems to be a generic term, applied to those stones, which consist principally of *hornblend*.

SECTION VIII.——Sand-Stone or Free-Stone.

Sand-stone is composed, generally, of grains of quartz, (*see granite*) united by a cement, which is never very abundant, and often, indeed, nearly or quite invisible. These grains are sometimes scarcely distinguishable by the naked eye, and sometimes their magnitude is equal to that of a nut or an egg.

The cement is variable in quantity, and may be calcareous or merely argillaceous, or siliceous. When siliceous, the mineral much resembles quartz. The texture of some sand-stones is very close, while that of others is so loose and porous, as to permit the passage of water.

Some varieties are sufficiently hard to give fire with steel, while others are friable, and may be reduced to powder, even by the fingers; this is often the case with those sand-stones whose cement is marly.

Its fracture is always granular or earthy; in some instances it may, at the same time, be splintery. Some sand-stones have a slaty structure, arising from scattered plates of mica, and have been called *sand-stone slate.*

Its most common color is gray or grayish, it is sometimes redish, or redish brown. In some cases the color is uniform, in others variegated.

Among the varieties are,

1. *Red Sand-Stone.* The grains of this variety are usually coarse, and united by an argillaceous cement, which is at the same time feruginous; hence the dark redish, or redish brown color, which it presents.

2. *Variegated Sand-Stone.* This presents a variety of colors; as yellow, green, brown, red, and white, which are usually arranged in stripes, or zones, either straight or wavering. It has commonly a close texture and fine grain; but it very often embraces roundish masses of clay, which often fall out when exposed to the weather, and diminish its value for the purposes of architecture.

3. *White Sand-Stone.* This includes many of the more common and valuable varieties of sand-stone. Its color is whitish gray, or gray, and generally uniform; but sometimes it is marked with redish spots. Its cement is often calcareous. It is well adapted for various uses in the arts.

Sand-stone is, in general, more or less distinctly stratified. Its beds are very often nearly or quite horizontal; but sometimes, especially in the older varieties, they are much inclined, or even vertical. Sometimes also, when in the vicinity of primitive mountains, its beds are thin, and much bent or waved. Beds of sand-stone are sometimes intersected with fissures perpendicular to the direction of the strata, and hence fall into tabular masses, which are often very large.

Sand-stone is found in various parts of the United States, and is, in some of its varieties, very useful in the arts. It is frequently known by the name of *free-stone.* When sufficiently solid, it is employed as a building stone. In most cases, it is of moderate hardness, and cuts equally well in all directions. Some varieties naturally divide into prismatic masses. It is sometimes used as mill-stones, for grinding meal, or for wearing down other minerals, preparatory to a polish. These stones, when, rapidly revolving, have been known to burst with a loud and dangerous explosion. When the texture is sufficiently loose and porous, it is employed for filtering water. Some varieties are used for whet-stones.

Sand-stone is used for buildings, in various parts of Europe. In Africa, the temple of Hermopolis is composed of enormous masses of this stone. In America, the Capitol at Washington is of the Potomac free, or sand-stone, likewise the facade of St. Paul's Church, in Boston.

SECTION IX.——Gneiss.

This rock, like granite, is composed of *feldspar*, *quartz*, and *mica*. But there is, in gneiss, less feldspar and more mica, than in granite; but even in this substance the feldspar appears in many cases to be the predominant ingredient. Its structure is always more or less distinctly slaty, when viewed in the mass; although individual layers, composed chiefly of feldspar and quartz, may possess a granular structure. The layers, whether straight or curved, are frequently thick; but often vary considerably in the same specimen; and when the mineral is broken perpendicular to the direction of the strata, its fracture has commonly a striped aspect. It splits easily in the direction of the strata, especially when a separation is made in a layer of mica. When gneiss is broken in the direction of the strata, the mica often seems more abundant than the other ingredients, but when seen on the cross fracture, it obviously exists in less proportion than the feldspar or quartz.

The plates, or foliae of mica, are usually arranged parallel to the direction of the strata, and in some varieties are chiefly collected into thin parallel layers, separated by those of feldspar and quartz. The grains of feldspar are often flattened in the direction of the strata.

The feldspar is usually white, or gray, sometimes with a tinge of yellow or red. The quartz is ordinarily grayish white; and the mica is often black, but sometimes gray.

The hardness of gneiss is variable; and the feldspar and mica are subject to the same changes as when they exist in granite.

Gneiss, like granite, never embraces any petrifactions, and is always a primitive rock.

When gneiss occurs with granite, it usually lies immediately over the granite; or, if the strata be highly inclined, it appears rather to rest against the granite, than to be incumbent upon it.

This rock, as has been intimated, assumes sometimes a granular structure, and passes, by imperceptible shades, into granite.

Mountains, composed of gneiss, are seldom so steep as those of granite.—This rock is abundant in the United States. It is useful for many purposes, in consequence of the facility with which it splits into masses of regular form.

SECTION X.——Mica-Slate.

Mica-Slate is essentially composed of *mica* and *quartz*, (*see granite*) which are in general, more or less intimately mingled; but sometimes the two ingredients alternate in distinct layers. Although the proportions of mica-slate are variable, the mica usually predominates.

The quartz is most frequently grayish white; but the mica may be whitish, or gray, bluish gray, or greenish, brownish, deep blue, or nearly black.

Its structure is always distinctly slaty, more so than that of gneiss; and its masses are often very fisile. The layers are sometimes straight, and sometimes undulated. In some varieties the texture is very fine, and the foliae of mica so small, that they are scarcely discernible by the eye, unless their aggregation be previously destroyed by heat.

This rock has often a very high lustre, when viewed by the reflected rays of the sun. It is, however, subject to decomposition, by which its aspect is much altered.

Mica-slate is a primitive rock; but seldom appears in high, steep cliffs, like those of granite. When it forms hills, the summits are usually much rounded. It abounds in ores, which exist both in beds and veins; but more frequently in beds. It is less abundant in the United States than gneiss. It is sometimes split into tabular masses, and employed for many common purposes. It is extremely useful in constructing the hearths and sides of furnaces for smelting iron.

SECTION XI.——Slate.

Slate is an argillaceous stone, characterized by easily splitting into large, thin, and straight layers, or plates, which are sonorous when struck by a hard body. It is dull, or has only a feeble lustre. Its colors are blackish gray, or bluish black, bluish, or redish brown, or greenish, &c.

It belongs both to secondary and primary rocks. Its structure *en masse*, is tabular; the small structure lamellar; the cleavage of the laminae being parallel with the tables.

Slate rocks vary in hardness, but they yield to the knife. They consist of an intimate intermixture, in various proportions, of siliceous earth, alumine, and iron; and sometimes contain a portion of lime, magnesia, manganese, and bitumen. Slate forms entire mountains, and sometimes distinct beds, alternating with other rocks. It most frequently rests on granite, gneiss, and mica-slate.

As this substance forms the most light, elegant, and durable covering for houses, and is, of course, of considerable value; it is rather surprising that so much indifference prevails respecting the search for it, in those districts where common slate, or *clay slate*, abounds. We believe all the roof slate quarries at present worked, are those which accident has discovered. This neglect is the more remarkable, when we consider the great expense frequently incurred for coal, a substance of less value in proportion to the weight.

All the best beds of roof slate, it is believed, improve as they sink deeper into the earth; and few, if any, are of a good quality near the surface, or are indeed suitable for the purpose of roofing. There cannot be a doubt, that many beds of slate, which appear shattered and unfit for architectural use, would be found of good quality a few yards under the surface; for the best slate, in many quarries, loses its property of splitting into thin laminae, by exposure to the air.

Though the specific gravity of slate from different quarries is the same, yet all the sorts are not capable of being split into an equal degree of thickness. It is good slate which will split into laminae of one eighth of an inch in thickness. It then weighs rather more than 26 ounces to a square foot, when applied to the covering of a roof. In some instances, slate of a thinner quality is used, where cheapness rather than durability is the principal object of the architect. According to an estimate of Dr. Watson, the relative weights of a covering of the following different materials, for forty-two square yards of roof, are

Copper, - -	4 Cwt.
Fine Slate, - -	26 "
Lead, - -	27 "
Coarse slate, - -	36 "
Tile, - - -	54 "

Slate, to be of a good quality for building, besides possessing the property of splitting into thin laminae, should resist the absorption of water; to prove which, it should be kept some time immersed in water; being weighed before and after the immersion, wiping the surface dry; it is obvious that the slate, which gains the least weight by this process, is the least absorbent. It should resist the process of natural decomposition by air and moisture; this depends on its chemical composition and compactness, and is shown by its resisting the process of vegetation. That slate which is most liable to decay, will be the soonest covered with lichens, mosses, &c. The hardness of slate principally arises from the silex it contains, which is of all earths the least favorable to vegetation. Those slates which are the hardest, when first taken from the quarry, and which have the least specific gravity, are to be preferred; for the increase in weight is owing to the presence of iron; to which slate and other stones, in some measure, owe their decomposition; while alumine renders them soft and absorbent.

Slate is so durable, in some cases, as to have been known to continue sound and good for centuries. However, unless it should be brought from a quarry of well reputed goodness, it is necessary to

try its properties, which may be done by striking the slate sharply against a large stone, and if it produce a complete sound, it is a mark of goodness; but if in hewing, it does not shatter before the edge of the instrument, commonly used for that purpose, the criterion is decisive. The goodness of slate may be farther estimated by its color; the deep blue-black kind, is apt to imbibe moisture, but the lighter blue is always impenetrable. The touch, also, in some degree, may be a good guide, for a good firm stone feels somewhat hard and rough, whereas an open slate feels very smooth, and as it were greasy. Another method of trying the goodness of slate, is to place the slate-stone lengthwise, and perpendicularly in a tub of water, about half a foot deep, care being taken that the upper, or unimmersed part of the slate, be not accidentally wetted by the hand, or otherwise; let it remain in this state twenty four hours; and if good and firm stone, it will not draw water more than half an inch above the surface of the water, and that, perhaps, at the edges only, those parts having been a little loosened in hewing; but a spongy, defective stone will draw water to the very top.

Roof slate is found in Pennsylvania, on the banks of the Delaware, about 75 miles from Philadelphia, of a good quality. In New-York, at New Paltz, Ulster County; and at Rhinebeck, Duchess County. In Dummerston, Vermont, it exists in strata nearly vertical; it is also found at Rockingham, and Castleton, where it is of a pale red. It exists in Maine, at Waterville, and Winslow, on the Kennebeck river.

Extensive quarries of slate, of a good quality, are worked near Bangor, England, this slate is exported in large quantities to various parts of the world.

It may be noticed, that in laying of this material, a bushel and a half of lime, and three bushels of fresh water sand, will be sufficient for a square of work; but if it be pin plastered, it will take about as much more; but good slate well laid and plastered to the pin, will lie an hundred years; and on good timber a much longer time. It has been common to lay the slates dry, or on moss only, but they are much better when laid with plaster.

SECTION XII.——Soap-Stone, or Steatite.

All the varieties of soap-stone are so soft, that they may be cut by a knife, and in most cases, scratched by the finger nail. Its powder and surface are soft, and more or less unctuous to the touch. It is seldom translucent, except at the edges. Its fracture is in general splintery, earthy, or slaty, with little or no lustre.

By exposure to the heat, it becomes harder, but is almost infusible by the blow pipe. It appears to be essentially composed of silex, magnesia, and perhaps alumine.

The common variety is usually solid with a compact texture; its surface is often like soap to the touch; but sometimes it is found of a considerable degree of hardness.

Its color is usually gray or white, seldom pure, but occasionally mixed with yellow, green, or red, and is sometimes a pale yellow, redish, or green of different shades. The colors sometimes appear in spots, veins, &c.

Its specific gravity usually lies between 2. 58 and 2. 79—when solid it is somewhat difficult to break. Before the blow-pipe it whitens and becomes hard, and is with difficulty reduced into a whitish paste or enamel, often however only at the extremity of the fragment. Some specimens have yielded by analyzation, silex, 64 parts, magnesia, 22. alumine, 3. water, 5. iron and manganese, 5.

Soap-stone occurs in masses, or veins, or small beds, in primitive and transition rocks, more particularly in serpentine. It is sometimes mixed with talc, mica, quartz and asbestus; or is found incrusted with other minerals.

This stone is not uncommon. It is found in various parts of the United States. Among the best quarries for fire-proof stone, is that of Francestown, New-Hampshire. It occurs also, in Connecticut, near New Haven, and at Oxford, Grafton, and Athens, in Vermont.

Soap-stone, on account of its softness, is wrought with the same tools as wood. It receives a tolerable polish, and is sometimes used in building, but is not always durable. It is, however, of great importance in the construction of fire places and stoves, and is extensively used for this purpose. Slabs of good soap-stone, when not exposed to mechanical injury, frequently last eight or ten years, under the influence of a common fire on one side, and of cold air on the other. It grows harder in the fire, but does not readily crack, nor change its dimensions sufficiently to affect its usefulness. Owing to the facility with which it is wrought, its joints may be made sufficiently tight without dependence on cement.

It is often wrought into various utensils by turning, and is advantageously employed for aqueducts. It has been found to be one of the best materials for counteracting friction in machinery, for which purpose it is used in powder, mixed with oil. It has also been employed for the purpose of engraving. By being easily cut, when soft, it may be made to assume any desired form, and afterwards rendered hard by heat; it then becomes susceptible of a polish, and may be variously colored by metallic solutions.

SECTION XIII.——Gypsum.

Gypsum is a term applied in its restricted sense to those varieties of sulphate of lime, which have a *fibrous* or *granular* structure, being the result of confused crystallization, and to those, whose texture is *compact*, or earthy. It is a substance that is interesting on account of its uses in agriculture and the arts. Its colors are commonly white or gray, sometimes shaded with yellow, red, or variously mingled.

It occurs in compact masses, sometimes granular, and sometimes in parallel fibres. Though sometimes coarse, the fibres are often

fine and delicate, glistening with a pearly satin lustre. Its fracture is foliated, sometimes splintery; it is generally translucent, often in amorphous masses; but not unfrequently crystallized. It is less hard than carbonate of lime. Its specific gravity usually lies between 2. 26 and 2. 31. By the blow-pipe it may be melted, though not very easily, into a white enamel, which shortly falls into a powder. It does not effervesce with acids, if it be pure sulphate of lime. It is soluble in about 500 times its weight of water. It does not burn to lime.

It is composed of 32 parts of lime, 46 of sulphuric acid, and 22 parts of water; but it is often contaminated with small quantities of carbonate of lime, alumine, silex, and oxide of iron. Some varieties are employed in sculpture and architecture under the name of alabaster; the same name is also given to some varieties of carbonate of lime.

The Plaster Stone, or Plaster of Paris, often contains foreign ingredients, which, in many instances, improve it as a cement.

This substance is found in abundance in many places, and has been extensively used for manure in dressing land, and appears to be useful in both clayey and sandy soils. It is also employed in the imitative and ornamental arts. Alabaster, both of the sulphate and carbonate kinds, has been used for the same purposes as marble in architecture and statuary; and being less hard it is more easily wrought; but is less durable and less valuable than marble. Gypsum, when deprived of its water of crystallization by burning or drying, constitutes *Plaster;* and this plaster. when mixed with a certain quantity of quick-lime, forms a good cement. *The Plaster of Paris* often contains, in its natural state, a sufficient quantity of carbonate of lime to constitute a good cement after calcination.

The finer kinds of *Plaster*, being reduced to powder, and mixed with water, have the property of becoming hard in a few minutes, and of receiving accurately the impressions of the most delicate models. It is extensively employed in *stucco* work, and in plastering rooms. It furnishes a delicate, white and smooth material for architectural models, impressions of seals, &c.; and in the art of stereotyping it is indispensable. In stucco, various colors, previously ground in water, may be introduced. All these works, when dry, are susceptible of a polish.

The Temple of Fortune, called Seja, appears to have been built with some variety of sulphate of lime. It had no windows, but transmitted a mild light through its walls.

SECTION XIV.——Puzzolana.

This substance is of volcanic origin. It usually occurs in small fragments, or friable masses, which have a dull, earthly aspect and fracture, and seems to have been baked. Its solidity does not exceed that of chalk. It is seldom tumefied, and its pores are neither

large or numerous. Its colors are gray or whitish, reddish or nearly black.

By exposure to the heat it melts into a black slag. A variety examined by Bergaman, yielded 55 to 60 parts of silex, 19 to 20 of alumine, 15 to 20 of iron, and 5 to 6 parts of lime. It often contains distinct particles of pumice, quartz and scoria.

This substance is extremely useful in the preparation of a *mortar*, which *hardens* quickly, even *under water*. When thus employed it is mixed with a small proportion of lime, perhaps one third. It has been supposed that the rapid induration of this mortar arises from the very low oxidation of the iron. If the mortar be a long time exposed to the air, previous to its use, it will not harden. The best puzzolana is said to occur in old currents of lava; but when too earthy it loses its peculiar properties. That which comes from Naples is generally gray.

SECTION XV.——Tras, or Terras.

The nature of this is similar to some varieties of puzzolana; and it contains nearly the same principles, but with a greater proportion of lime. Its hardness is, however, much greater, than that of puzzolana. Its color is brownish or yellowish; and its fracture earthy and dull. It has been found chiefly near Andernach, in the vicinity of the Rhine.

It is said to be decomposed basalt. It forms a durable water cement when combined with lime. It is the material which has been principally employed by the Dutch, whose aquatic structures probably exceed those of any other nation in Europe. Terras mortar, though very durable in water, is inferior to the more common kinds, when exposed to the open air.

SECTION XVI.——Quarrying.

The common methods of working and managing different sorts of quarries, are in general pretty well understood, by such quarrymen as are constantly employed in the business. The materials are indicated by the appearance of the surface of the earth, the nature of the substances in the vicinity, or by digging down and opening the ground by spades and other tools, or by boring with an auger made for the purpose.

The great value to mankind of such materials as coal, iron ores, &c. as well as of building materials, should induce proprietors of land to cause a more diligent and scientific search for these hidden treasures, than has been hitherto practised in this country. It may also be suggested, that it would be highly beneficial and advantageous, if mineralogists, and those who have an acquaintance with

such substances, were to turn their attention towards the appearances and accompaniments, which point out such useful concealed matters; as it might greatly facilitate the search for them, and frequently lead fortuitously to their discovery. In searching for most sorts of mineral substances, coals, and some other matters, the use of the *borer* is almost constantly resorted to; but with regard to limestone, free-stone, granite, &c., digging down into the earth is the mode commonly employed in the first instance, in consequence of such substances being obviously present in sufficient quantities to be wrought with advantage.

When it has been ascertained that the material exists in sufficient quantity to warrant the working of the quarry, much time and expense will be saved, by proceeding in a correct manner in the first opening of it.

Instead of beginning to dig at the top, by which means the progress of the workmen will soon be impeded by accumulating rubbish, or the rushing in of water, it would be far preferable to commence on one side of the elevation which contains the material, having previously ascertained which way the rocks incline or dip, and gradually approach the quarry, on this side; clearing away the dirt and superincumbent substances as low down as the nature of the ground will admit. In this manner, the mouths or openings of the quarries may be easily kept free, and the water carried off; at the same time, the materials may be operated upon, and removed with the greatest facility. If the nature of the situation admits of the opening of a quarry in this manner, the more convenient method of working it is, by gradations or steps. That is, the stone is first taken from the top to an uniform depth for a considerable distance back; then another stratum or layer is removed till it approaches within some distance of the first, when a third is began, and so on; so that the quarry presents the appearance of steps, or horizontal planes one above the other. This method affords facilities for removing the stone, or materials without the aid of expensive machinery.

There is often a great difference in the quality of the material in the same quarry. Those portions, which are nearest to the surface, are sometimes mixed with foreign ingredients, that impair their value, or render them useless.

The stones are obtained of suitable dimensions by blasting, by splitting with iron wedges set in a direct line, and driven with much force by a sledge or hammer. Advantage is often taken of natural fissures which are in straight lines, and often at right angles.

Granite, and the stones related to it, although of great hardness, will split very straight by means of wedges. The pieces are afterwards wrought into the form to be used, either at the quarry, which diminishes the expense of transportation, or removed in a rough state, and thus used in building; or finished, as may be deemed expedient.

In working granite, and materials of a similar nature, it is first lined, or marked into the form desired. The workman then forms the edge all round by means of a chissel and hammer, making it smooth and straight to the depth of one or two inches; he after-

wards breaks off the larger portions with a hammer made in a peculiar form, and kept sharp; with this instrument he continues to take off the inequalities of the surface, till it has the requisite smoothness.

Sand-stone, free-stone, and materials of the like nature, being less hard than granite, are more easily wrought by a similar process. Some of them admit of a considerable degree of polish.

Marble and soap-stone are taken from the quarries in large masses, and afterwards sawed, either by hand, or in mills constructed for the purpose, and then polished, (*see Marble and Soap-Stone.*) Slate, in some instances, is obtained by blasting. It is sometimes dug out by one set of men, split by another, and formed into slates by a third; for which purposes, flat crow-bars, slate-knives, and axes are employed. It is often divided into three sorts, as firsts, seconds, and thirds, which vary in quality and price.

Sand and gravel are mostly dug out from the sides of banks, and other places; and but rarely obtained by sinking the quarries into the more level parts of the ground, though this method is sometimes practised. The materials are commonly raised, simply by digging with spades; and thrown into carts, in many cases, from the quarries, or pits themselves.

The removal of materials from quarries, is effected by means of inclined planes, of rail-ways, or by various machines constructed for the purpose, such as the windlass, the pulley, &c. adapted in each instance to the situation of the quarry, and the circumstances of the case.

The Quincy stones are raised from their beds by the means of a windlass worked by a horse, and received upon cars, which run upon inclined rail-ways, within a few feet of the quarry; from thence they are conveyed to the sea on a rail-way, and transported in various directions. By the descent of a loaded car on the inclined rail-way at the quarry, an empty car is drawn up.

The greatest difficulty incident to working quarries, is that of *draining*, and freeing their bottom parts from injurious water; so that they may be in a fit state to be wrought with ease and advantage.

The most usual remedies, resorted to in this difficulty, are pumps, worked by wind, by horse, steam, or other powers; but these often prove ineffectual in removing the water completely, and new quarries are opened near the old ones. But an attention to certain principles, in regard to the nature of the soil, and the courses of subterraneous waters, may often lead to more cheap, expeditious, and effectual remedies.

It is now well understood, that most springs, and subterraneous collections of water are formed and supplied from such grounds as lie higher than that of the places where the waters are met with, which, in consequence of their being of an open and porous nature, admit the rain and other sorts of moisture to filtrate and pass freely through them. These waters descend to great depths before they become impeded by some sort of impenetrable stratum, or layer of a solid or stony nature, as clay, or compact rock. It may happen, in sinking quarries, that beds of quicksand may be

met with, which are so full of water, that to penetrate through them will be very difficult; and from a knowledge that the water proceeds from the porous ground that lies above them, it may be practicable to intercept and cut off the greater part of it before it reaches the sand beds in the quarries, by the means of boring into and tapping the water at the *tails* of the banks of this nature, provided, that the ground declines lower than the place where the sand is found in the quarries, which may be done at a trifling expense, in comparison to the common remedies.

But in order to accomplish this intention, it will be necessary, in ascending from the quarry, to ascertain if at the place higher, on the declivity, any porous stratum, bed of rock, sand or gravel, *tails* out, which may convey the water contained in it to the sand bed, which is below in the works; and where any such is found, to cut and bore into it, in such a manner as to form a drain, that is capable of conveying off the water, which would otherwise have descended into the quarry.

But although this part of the business may have been accomplished, and the supply of water from the higher ground entirely cut off, a sufficient quantity to injure and inconvenience the working may yet continue to drain from the sides of the sand beds, though they should happen to dip towards the lower ground; in which cases, however, this water may be drawn off readily to some particular point.

In order to effect this, it should be ascertained, at what particular place in the low ground the sand terminates, or *tails* out, which is the best accomplished by means of proper levelling; and if there should be any appearance, in this place, of the water's having a natural outlet, it may, by making it into a deep drain, cause the water effectually to be drawn off. Where, however, there happens to be a deep, impervious layer of clay, or other matter of a similar nature, placed above, or upon the termination, or tail of the sand, the drain need only be cut down to it, or a little way into it, as by means of boring through it, a ready and easy passage may be given to the whole of the water, contained in the sand bed, or porous stratum.

It is of material importance to lay dry all such grounds as are situated higher, but contiguous to quarries, for the above stated reasons, and it may in general be accomplished with but little difficulty and expense, by adopting the same principles, and the same means.

This is the mode that is to be pursued in preventing the effects of the water, or cutting it off, when met with in sinking quarries. It proceeds on the principle of the dipping position of the strata with the natural inclination of the land.

It frequently happens, that a body of the same stone, which is of a close and compact nature, is found lying under one, which has a more open and porous texture, with fissures and cracks in it, that are admissible of water, in the upper body or layer, in such a manner that none can pass through it to the inferior, or still deeper, open stratum, or bed; and on sinking, or cutting through this compact bed, another layer is met with, which is of so porous a nature as to admit the reception of any water, that may come

upon it. And sometimes a bed of gravel, or sand is found under that of close stone, which being capable of absorbing any water that may come upon it, and which is far better suited for the purpose of clearing the upper bed of stone from water, than the stratum of open stone itself. Therefore, when this is ascertained to be the case, and the water is kept up by the second bed of stone, so as to be injurious to the working of the upper bed, and which will be equally so in working the second; the work may be greatly freed by boring through the close bed of stone, and letting the water down into the more porous one below, or into a stratum of dry sand, or gravel, should there be such a one underneath it. But instead of boring, the sinking of small pits through the close stone, is a more effectual way of letting down the water.

In all such cases as these, boring or sinking pits through the solid stratum into a porous substance, or layer, underneath, is the most advisable, and, at the same time, the least expensive method, that can be pursued.

TABLE.

The following table shows the weight of granite stone in lbs. and 100ths, both in a cubical and cylindrical form; the dimensions being given. The first column of figures denotes a piece of stone to be 1, 2, 3, &c. inches square, or in diameter; each piece being 12 inches in length. Columns 2 and 3 are the mean weight of common stone; 4 and 5 the weight of the Quincy stone; 6 and 7, the weight of a species of coarse granite, found at Sandy Bay, in Massachusetts.

	MEAN WEIGHT OF STONE IN GENERAL.		QUINCY GRANITE.		SANDY BAY GRANITE.	
	Square.	*Cylindric.*	*Square.*	*Cylindric.*	*Square.*	*Cylindric.*
Estimated at one foot long.						
1	1,07	,86	1,16	,95	1,17	,95
2	4,33	3,45	4,65	3,80	4,68	3,80
3	9,70	7,75	10,44	8,55	10,53	8,56
4	17,33	13,80	18,56	15,20	18,72	15,21
5	27,00	21,50	29,00	23,75	29,22	23,77
6	38,10	31,00	41,76	34,20	42,12	34,23
7	52,67	42,00	55,88	46,55	57,33	44,59
8	69,00	55,00	74,24	60,80	74,88	60,86
9	86,67	69,65	83,96	76,95	94,77	77,03
10	107,33	86,00	116,00	95,00	117,00	95,10
11	130,00	104,00	140,36	114,95	141,57	115,07
12	155,00	124,00	167,04	136,80	168,48	136,94
Estimated at five feet long.						
1	5,35	4,30	5,80	4,75	5,85	4,75
2	23,65	17,25	23,20	19,00	23,40	19,40
3	48,50	38,75	52,20	42,75	52,65	42,80
4	86,65	69,00	92,80	76,00	93,60	75,05
5	135,00	107,50	145,00	118,75	146,10	118,85
6	190,50	155,00	200,80	171,00	210,00	171,15
7	263,35	310,00	379,20	232,75	286,65	222,95
8	345,00	275,00	371,20	304,00	374,40	304,30
9	433,35	348,00	419,80	384,75	473,85	385,15
10	536,65	430,00	580,00	475,00	585,00	475,50
11	650,00	520,00	701,80	574,75	707,85	575,35
12	775,00	620,00	835,20	680,00	842,40	684,70
Estimated at ten feet long.						
1	10,70	8,60	11,60	9,50	11,70	9,50
2	43,30	34,50	46,40	38,00	56.80	38,00
3	97,70	77,50	104,40	85,50	105,30	85,60
4	173,30	138,00	185,60	152,00	187,20	152,10
5	270,00	215,00	290,00	237,50	292,20	237,70
6	381,00	310,00	417,60	342,00	421,20	342,30
7	526,70	420,00	558,40	465,50	573,30	445,90
8	690,00	550,00	742,40	608,00	748,80	608,60
9	866,70	696,00	839,60	769,50	947,70	770,30
10	1073,00	860,00	1160,00	950,00	1170,00	951,00
11	1300,00	1040,00	1403,00	1149,00	1415,70	1150,70
12	1550,50	1240,00	1670,40	1368,00	1684,80	1369,40

RULES

FOR MEASURING HAMMERED GRANITE STONE,

ADOPTED APRIL, 1829.

PREAMBLE.

To prevent misunderstanding between the STONE CUTTERS, the MASONS and their employers, in relation to the admeasurement of hammered Granite Stone, it was deemed expedient, that a meeting be called of those engaged in the business, to endeavor to agree upon some uniform system, that shall be equally intelligible to all parties; said meeting was held in March last, when a Committee of eleven persons were chosen, to take the subject into consideration, and report at a subsequent meeting. At a meeting in April, said committee reported, that they had attended to the duty assigned them, and after mature deliberation, have agreed on the following Rules, which, if adopted, will, in their opinion, greatly promote the interest, as well as the harmony of all concerned in the business, whether purchaser or vender; at which meeting said Rules were adopted by the unanimous vote of all present, who then affixed their signatures to the same, since which, others have subscribed their names.

Boston, May 17, 1829.

RULES, &c.

SECTION 1. ASHLER STONES are to be measured on their fronts, quoin heads, and reveals against doors, windows and recesses.

SEC. 2. HEADERS, or binders that make the thickness of the wall, are to be measured as Ashler work, adding their beds, or builds.

SEC. 3. DOUBLE HEADED QUOINS, not less than 9 inches each head, are to be measured as Ashler work, adding their beds, or builds.

SEC. 4. WINDOW CAPS for Ashler work, are to be measured on their fronts, under sides that show, and reveals.

SEC. 5. WINDOW SILLS for Ashler work, are to be measured on their tops and fronts, the whole thickness of their rise, and half their under sides.

SEC. 6. BELT STONES for Ashler, or Brick work from 7 to 9 inches rise, and the usual thickness of Ashler work, are to be cast at the rate of a superficial foot to each foot in length.

SEC. 7. ARCH STONES in Ashler work, are to be measured their extreme lengths by their extreme widths, adding the returns and reveals.

SEC. 8. ASHLER STONES for Pediments or Gable-ends of buildings, and other similar purposes, are to be measured their extreme lengths, by their extreme widths.

SEC. 9. PLINTHS are to be measured on all parts that show, and half the rough hammered parts.

SEC. 10. PILASTERS are to be measured on their fronts, returns and reveals.

SEC. 11. IMPOSTS are to be measured on their fronts, ends and beds, or builds.

SEC. 12. POSTS or CAPS, are to be measured on four sides, and the ends of caps that show.

SEC. 13. POSTS in or out of square, are to be measured on four sides, squaring from their extreme points.

SEC. 14. DOOR SILLS, under Posts, are to be measured on their tops, fronts and ends, and half the parts hammered under the ends.

SEC. 15. WINDOW SILLS between Posts, are to be measured on their tops, under-sides, and their whole rise.

SEC. 16. ARCH CAPS and BLOCKS, that make the thickness of the wall, are to be measured on four sides, the extreme lengths by their extreme widths.

SEC. 17. BELT STONES that make the thickness of the wall, are to be measured on their fronts, beds and builds, and ends that show.

SEC. 18. COURSES of STONES that make the thickness of the wall, are to be measured on their fronts, beds and builds.

SEC. 19. DOOR STEPS, are to be measured on their tops, fronts and laps, and the ends that show, which ends are to be measured at the rate of a superficial foot to each foot on the width.

SEC. 20. RETURNS for Steps, from 6 to 10 inches rise, are to be measured at the rate of a superficial foot to each foot in length.

SEC. 21. PLATFORM STONES are to be measured as Steps, when two or more are required, half the edges for joints are to be added.

SEC. 22. SPIRAL STEPS are to be measured their extreme length by their extreme width, rise and laps, and ends that show.

SEC. 23. FENCE STONES are to be measured on their fronts, tops and inside, where hammered, and ends that show.

SEC. 24. POSTS that stand in the ground, are to be measured on four sides and tops, and half measurement of the rough parts in the ground, according to the dimensions of the hammered parts.

SEC. 25. CELLAR DOOR CURBS are to be measured on their tops and inside, or rise, the whole length of each stone, the rabbets are to be measured the length of each stone by the running foot.

SEC. 26. CELLAR WINDOW CURBS are furnished by the piece.

SEC. 27. WELL CURBS are to be measured on the outside and tops, where hammered with the jogs and corresponding ends.

SEC. 28. SESS POOL CURBS are to be measured as Cellar Door Curbs.

SEC. 29. GUTTER STONES are to be measured on the top side by the superficial foot; Cutting Gutters to be charged extra.

SEC. 30. EDGE STONES are to be measured by the running foot, double measure when circular.

SEC. 31. CUTTING SCROLES, JOGS, RABBETS, GROVES, GUTTERS, and DRILLING HOLES, are extra work, and do not add to, or diminish from the measurement of the work.

SEC. 32. VAULT STONES are to be measured on three or four sides, as may be hammered, and the ends that show. Floor and Ceiling Stones more than 9 inches in thickness, are to be measured on one side and two edges, and the ends that show; when 9 inches or less thickness, on one side and ends that show.

SEC. 33. All STONES not included in the foregoing specifications, on account of their irregular form or unfrequent use, should be measured as nearly as possible according to the rules applying to those which resemble them.

SEC. 34. Those which differ in all respects, must be furnished by the piece.

Sec. 35. The two foregoing observations apply to Ornamental Work, the parts of which are so minute, and generally of such complicated forms, that no system of rules sufficiently short and comprehensive, can with any utility be adopted; with regard however to two or three parts of Ornamental Work, in common use, it may be well to state, that Cornice is usually furnished by the running foot; Bases, Columns and Capitals, by the piece.

Sec. 36. All Circular Work to be charged extra, and the mode of measurement should be agreed upon at the time said work is contracted for.

William Austin.

Gridley Bryant,
Benjamin Blaney,
Jacob Bacon.

William Crehore,
Samuel Currier,
Levi Cook,
Conrad C. Carleton.

James C. Ewer, Jr.,
George H. Ewer.

Joseph Glass.

Ephraim Harrington,
Thomas Hollis,
Charles G. Hall.

Samuel R. Johnson,
Nathaniel Jewett.

Sewall Kendall.

Allen Litchfield, Jr.,
Ward Litchfield,
Francis Lawrence.

James McAllaster,
Caleb Metcalf,
Samuel Marden,

Luther Munn.

Jonathan Newcomb,
Cushing Nichols.

Alexander Parris,
James Page,
William Packard,
Lot Pool.

Joseph Richards,
John Redman,
Wyatt Richards,
Alanson Rice.

Edward Shaw,
Zephaniah Sampson,
Franklin Sawyer,
Asa Swallow,
James S. Savage,
Amos C. Sanborn.

Job Turner,
Joseph Tilden.

Charles Wells,
William Wood,
Mordecai L. Wallis,
Richard Witherell,
Henry Wood,
Jeremiah Wetherbee,
Salmon Washburn.

CHAPTER II.

SECTION I.——Clay.

The substances included under this term, are mixtures of silex, or the ingredient of the common Gun flint, and alumine; they sometimes contain other earths, or metallic oxides, by the latter of which, some varieties are highly colored. Their hardness is never great; they are easily cut by a knife, may in general be polished by friction with the finger nail, and are usually soft to the touch. When immersed in water, they crumble more or less readily, and become minutely divided. Many clays, when moistened, yield a peculiar odor, called argillaceous; but this quality appears to be owing to the presence of metallic oxides, as perfectly pure clays do not possess it.

The substances which are properly termed clays may, by a due degree of moisture and proper management, be converted into a paste more or less tenacious and ductile, which constitutes the basis of several kinds of Pottery. It possesses a greater or less degree of unctuosity, and is capable of assuming various forms without breaking. This argillaceous paste, when dried becomes in some degree hard and solid, and by exposure to a sufficient degree of heat, may be made to assume a stony hardness.

Clays have a strong affinity for water; hence the avidity, with which they imbibe it; hence also, they adhere more or less to the tongue or lips.

Clay, when composed of only silex and alumine, in any proportions, is infusible in a furnace, and even when somewhat impure, it resists a degree of heat without melting. But the presence of other earths, particularly of lime, or of a large quantity of oxide of iron with a little lime renders it fusible. By exposure to heat, it diminishes in bulk, and loses somewhat of its weight by the escape of water.

Although clay is essentially composed of silex and alumine, these ingredients exist in various proportions. In most cases silex predominates, being in the proportion of two, three, or even four parts to one of alumine; sometimes the proportions are nearly equal, and in some cases the alumine predominates. The power of alumine to impress its character on the compound, although present in less proportion than the silex, probably arises from a greater minuteness of its particles.

The color of clay may proceed from oxide of iron, or from some bituminous or vegetable matter. Hence some colored clays, when exposed to heat, become white by the destruction of their combustible ingredients, while others suffer merely a change of color, by the action of oxigen on the iron. The purer clays are white, or gray, and suffer little or no change by the action of fire.

The varieties of clay are numerous; the purest kinds are extensively used in the manufacture of porcelain ware; and those that are less pure are burnt into stone ware and bricks.

The common clays may be divided, in regard to their utility, into three classes. The *Unctuous*, *Meagre*, and *Calcareous*.

The unctuous contains, in general, more alumine than the meagre, and the siliceous ingredient is in finer grains; when burnt it adheres strongly to the tongue, but its texture is not visibly porous. When containing little or no oxide of iron, it burns to a very good white color, and is very infusible; pipes are made of it, and it forms the basis of the white Staffordshire ware. If it contains oxide of iron, sufficient to color it red, when baked, it becomes much more fusible, and can only be employed in manufacturing the coarser kinds of pottery.

Meagre clay is such, as, when dry, does not take a polish from rubbing it with the nail; it feels gritty between the teeth, and the sand which it contains is in visible grains. When burnt without addition, it has a coarse granular texture, and is employed in the manufacture of bricks and tiles.

Calcareous clay effervesces with acids, is unctuous to the touch, and always contains iron enough to give it a red color when baked. It is much more fusible than any of the preceding kinds, and is only employed in brick-making. By judicious burning it may be made to assume a semi-vitrous texture, and bricks thus made are very durable.

Clays are very abundant in nature, and contribute the most to the wants and conveniences of man, of all the earthy minerals.

SECTION II.——Brick-Making.

The clay for the purpose of making bricks, should be dug in the autumn, and piled in solid heaps. During the winter it should be broken up, and exposed in such masses, from day to day, as to become thoroughly penetrated by the frost.

In the spring, the clay is to be broken into small pieces, and shovelled over, in order to expel the frost. After this is done, it is thrown into pits and mixed with fine sand and a suitable proportion of water: the sand should be clear, free from lumps of marl and siline particles; siliceous sand is to be preferred, and the water must be fresh. The ingredients are to be worked over by the means of the shovel, treading, or the wheel, till they are properly incorporated, and are of a suitable consistency;—in this way they are prepared for the striker's bench.

In preparing for a brick-yard, the surface of the ground should be cleared, and levelled; a coat of sand, two or three inches in depth, is to be put upon it, and rendered as hard, and as smooth as is practicable, by passing a heavy roller several times over it when wet. After this, a thin layer of sand is sifted upon the surface, and a wooden scraper passed over it, in order to render it as smooth and even as possible. The yard should be of a size sufficient to contain the bricks that may be struck in two days.

Brick moulds are commonly made to contain six bricks each. The striker is prepared with two moulds, and a trough of water. When the prepared clay is shovelled on to the striker's table, he takes his mould from the trough of water, adjusts it on a thin, level board bottom, and with his hands wet, to prevent adhesion, strikes from the pile of mortar, or prepared clay, a quantity a little more than sufficient to fill one of the apertures of the mould, which he drops into it with considerable force, and presses it firmly down; he then strikes the surplus off with his hand, and thus proceeds, till all the apertures of the mould are filled.

A second person (called the carrier) now takes the full mould from the striker's table, to another part of the brick-yard, and puts it down bottom upwards. The bottom board is then drawn off diagonally, in order to preserve the edges of the bricks entire; the mould is raised, and the bricks left on the sand to dry. The carrier returns the empty mould to the striker's trough, takes the second full mould and deposits the bricks as before. The bricks are thus exposed in ranges till they are so dry as not to be easily defaced; they are then placed upon their edges and remain till they are dry enough to be put into hacks. The hacks are composed of alternate layers of bricks, the first layer is called *stretcher*, and the second *heder*; interstices, or spaces are left between the bricks from 3-8 to 1-2 an inch, so that the air may have a free circulation between them.

The bricks ought to remain in this situation till they are dry enough to go into the kiln, or at least, for six or eight weeks of dry weather. The hacks may be of the thickness of three or four bricks placed lengthwise, and six or eight feet in height. They are to be protected from storms by sheds erected for the purpose.

In forming bricks into a kiln, they are laid in benches, with arches, or apertures for the fuel. A bench is formed in this manner. Courses brick, or the stretchers, are laid lengthwise; and across the stretchers, or at right angles with them, are laid other courses, or heders, interstices are left between the bricks from 1-4 to 1-2 of an inch in thickness. The stretchers and heders alternate with each other; and four courses of them form a bench. Between every two benches, there is a space left, two brick's length in breadth, for arches. The arches are formed by the gradual projection of the courses in the two benches, about as far as the eighth course, where the courses of the benches, on each side of the space, meet, at the distance, generally, of thirty-two inches from the ground. The benches are commonly raised to the height of seven or eight feet. Thus the benches and arches alternate with each other, till the number is increased, as it may be deemed expedient. The bricks in the bench are placed on their edges, and care should be taken to preserve throughout the

interstices between their sides, so that the heat may percolate. At the top of the kiln, the outside walls should have an inclination inwards, of about one foot in seven of perpendicular height. The kiln is faced by refuse or unburnt bricks, laid up in clay mortar, extending around the whole exterior of the kiln, the thickness of the width of a single brick. The mouths of the arches are to be left open, and flat stones prepared for closing them, while the kiln is in the progress of burning.

The moulds used in the vicinity of Boston are commonly 8, 3-8 inches in length, 2, 1-8 in thicknes, and 4, 1-2 in width; and bricks, when burnt, vary from 8 to 7, 3-4 inches in length, and are about 4 inches in width, and 2 in thickness, according to the length of time, and the degree of heat, to which they have been exposed.

The burning is commenced with a moderate heat, in order first to expel the moisture. When this is done, the smoke changes from a great degree of blackness to a thin transparent glimmering.

Then the intensity of the heat is increased to as great a degree, as the material will bear, without being fused, which is continued till a contraction, or shrinkage, takes place at the top of the kiln, and at the ends of the arches opposite to those in which the fuel is placed. When this is the case, it is necessary to close the mouths of the arches, at which the fuel has been inserted, and to put it in at the mouths opposite. At the close of the process of burning, the arches are filled with hard wood and then closed, and the kiln is suffered to remain thus, till the bricks are sufficiently cool for handling, before they are exposed to the air.

A machine has recently been been patented, and put in operation in this vicinity, for preparing the materials for brick, which seems to possess many advantages over the common method. The machine consists of a wheel for mixing the mortar, and apparatus for filling the moulds, and is worked by horse or steam power. It possesses, among others, the following advantages; that of pulverizing the clay more thoroughly, and producing a more homogeneous and compact paste, and in consequence the bricks are less liable to crack in the operation of drying, or burning; and by being more firmly pressed into the moulds, they are less liable to absorb moisture from the atmosphere, and are rendered smoother; and as less water is required by this mode, in making the paste, the bricks do not require the same length of time in drying, while they are subject to shrink less in burning, than in the common method. And lastly, much time and labor are saved in the operation.

SECTION III.——Faced or Pressed Bricks.

These bricks are used to form the facing of walls in the better kind of structures, and are finished in a machine. The roughness and change of form, to which common bricks are liable, is owing, in part, to the evaporation of a portion of the water which the clay contains. To remedy the difficulty arising from this cause, the

bricks, after being moulded in the common manner, are exposed to the sun till they are nearly dried, retaining however, sufficient plasticity to be still capable of a slight change of form. The moulds, however, are somewhat larger than those of the common bricks, in order that the bricks, when pressed, may be of a sufficient size. The press machine is usually made of cast-iron, and contains a number of moulds arranged in a circle, or otherwise, so that the power is applied to them in succession, and the bricks pressed with rapidity. The mould is of sufficient thickness to resist about a ton's weight, applied to the top of a follower. The follower is fitted as near as practicable, to the inner side of the mould, and kept in a proper position to be forced through, when the moulds are removed from their beds. This is done by the means of a wheel, or slide, to which the mould is attached. The bricks, being pressed, are received on a carrying board.

The force is applied for pressing the bricks, by the means of a double purchase lever, or by the revolution of a wheel with rollers running on an oblique plane.

In this manner about five thousand bricks may be pressed off in a day, by the labor of two men and a horse.

The pressed bricks are of a superior quality in point of durability and elegance. They form a wall with a surface of great smoothness, and when carefully laid, produce a pleasing effect. These bricks are durable from their hardness and smoothness, being less liable to decomposition from the action of the atmosphere.

A patent was obtained in England, about the year 1795, by Mr. Cartwright, for an improved system of making bricks; of which the following extract will furnish all necessary information.

"Imagine a common brick, with a groove on each side down the middle, rather more than half the width of the side of the brick; a shoulder will thus be left on each side of the groove, each of which will be nearly equal to one quarter of the width of the side of the brick, or to one half of the groove, or rebate. A course of these bricks being laid shoulder to shoulder, they will form an indented line of nearly equal divisions, the grooves being somewhat wider than the adjoining shoulders, to allow for the mortar or cement. When the second course is laid on, the shoulders of the bricks, which compose it, will fall into the grooves of the first course, and the shoulders of the first course will fit into the grooves of the second, and so with every succeeding course. Buildings constructed with these bricks will require no bond timbers, as an universal bond runs through the whole building, and holds all the parts together; the walls of which will neither crack nor bilge without breaking through themselves. When bricks of this construction are used for arches, the sides of the grooves should form the radii of a circle, of which the intended arch is a segment. In arch work, the bricks may either be laid in mortar, or dry, and the interstices afterwards filled up by pouring in lime, putty, plaster of Paris, &c. Arches of this kind, having any lateral pressure, can neither expand at the foot, or spring at the crown, consequently they need no abutments; neither will they need any superincumbent weight on the crown, to prevent them from springing up. The centres may also be struck

immediately, so that the same centre, which never need be many feet wide, may be regularly shifted as the work proceeds. But the most striking advantage attending this invention, is, the security it affords against fire ; for, from the peculiar properties of this kind of arch, requiring no abutments, it may be laid upon, or let into common walls, no stronger than what are required for timbers, so as to admit of brick floorings."

SECTION IV.

The use of bricks in building, may be traced to the earliest ages, and they are found among the ruins of almost every ancient nation. The earliest edifices of Asia were constructed of bricks, dried in the sun, and cemented with bitumen. Of this material was built the ancient city of Nineveh. The walls of Babylon, some of the ancient structures of Egypt and Persia, the walls of Athens, the rotunda of the Pantheon, the temple of Peace, and the Thermae at Rome, were all of brick. The earliest bricks were never exposed to great heat, as appears from the fact, that they contain reeds and straw, upon which no mark of burning is visible. These bricks owe their preservation to the extreme dryness of the climate in which they remained, since the earth of which they were made often crumbles to pieces when immersed in water, after having kept its shape for more than two thousand years. This is the case of some of the Babylonian bricks, with inscriptions in the arrow headed character, which have been brought to this country. The ancients, however, at a later period, burnt their bricks, and it is these chiefly, which remain at the present day. The antique bricks were larger than those employed by the moderns, and were almost universally of a square form. Those of Rome appear to have been of three different sizes—the largest were about 22 inches square, and 2 1-4 inches thick ; the second size 16 1-2 inches square, and from 1 1-2 to 2 inches thick ; the smallest size about 7 1-2 inches square, and 1 1-2 thick. In order to secure, more effectually, the facing with rubble, the Romans placed in their walls, at intervals of every three or four feet, two or three courses of the larger brick, (*see plate* 35, *fig.* 6.) The larger bricks were used in the formation of arches, and in the openings of buildings.

The bricks of the Greeks were commonly cubical, and of different sizes. One size was a foot on all sides ; another kind fifteen inches ; the former was chiefly used in the construction of private, and the latter in public edifices. There was a third kind, a foot square, and six inches thick, and a fourth kind fifteen inches square, and seven and a half inches thick ; these two last kinds were called half bricks, and were used for the purpose of better effecting the construction of a bond, (*see plate* 34, *fig.* 4.) They also employed, as well as the Romans, another size, for ornamental walls, called net work, (*see plate* 35, *fig.* 7.) This net work had a beautiful appearance, but was liable to crack ; in consequence, according to

Palladio, there are no ancient specimens of this kind remaining. Vitruvius, however, states the form of these bricks to have been a parallelogram, six inches wide, and from twelve to twenty-four inches long.

The baked bricks of the ancients were generally made of two parts of earth and one of cinders, well tempered together. They were taken from the moulds, and left to dry in the sun for several days, and afterwards placed in a large furnace, ranged one over another, at some distance apart; the spaces between were filled with plaster, or a sort of strata of fine coal.

Besides bricks made of clay, the ancients also employed a kind of factitious stone, composed of a calcareous mortar. They were also in the habit of using bricks and stones, both rubble and wrought, in the same wall.

In a rubble wall, three courses of bricks were laid at intervals of two or three feet, for the purpose of binding the mass together; the angles were also supported by piers of stone or bricks, (*see plate* 35, *fig.* 5.)

In buildings of more magnificence, (*see plate* 35, *fig.* 6,) the rubble was concealed in the wall. The bottom of the wall was formed of six courses of large bricks, then courses of smaller bricks were laid up to the height of three feet. Then the wall was bound again with three courses of large bricks, and so on. Examples of this kind of wall still remain in the pantheon, and warm baths of Dioclesian.

SECTION V.——Tiles.

Tiles are plates of burnt clay, resembling bricks in their composition, and manufacture, and used for the covering of roofs. They are necessarily made thicker than slates, or shingles, and thus impose a greater weight upon the roofs. Their tendency to absorb water, promotes the decay of the wood work beneath them.

Tiles are usually shaped in such a manner that the edge of one tile receives the edge of that next to it, so that water cannot percolate between them. Tiles, both of burnt clay and marble, were used by the ancients, and the former continue to be employed in various parts of Europe. Floors, made of flat tiles, are used in many countries, particularly in France and Italy.

SECTION VI.——Compact Lime-Stone.

The uses and geological characters of this substance, render it peculiarly interesting. The term *compact*, however, as applied to this stone, must be received with some latitude; for, although its texture is often very close and compact, sometimes like that of wax, yet, in other instances, it is loose and earthy.

Among the numerous colors of compact lime-stone, the most frequent are the various shades of gray, such as smoke-gray, yellowish gray, bluish gray, reddish and greenish gray; it is also seen grayish white, grayish black; flesh red, with some deep tints of red and yellow; several of these colors often occur in the same fragment, which are distinguished by the epithet of *marbled*.

It usually occurs in extensive, solid, compact masses, whose fracture is dull and splintery, or even, and sometimes conchoidal. It is sometimes traversed by minute veins of calcareous spar, which reflect a little light; and some compact lime-stones are also slaty. Its hardness is somewhat variable. Its specific gravity usually lies between 2. 40 and 2. 75. It is opaque, and more or less susceptible of a polish.

Compact lime-stone is seldom, perhaps never, a pure carbonate; but contains from 2 to 12 per cent. of silex, alumine, and the oxide of iron, on the last of which its diversified colors depend. In fact, by increasing the proportion of argillaceous matter, it passes into marl. Some lime-stones, which effervesce considerably with an acid, are still so impure, that they melt rather than burn into lime.

The uses, to which compact lime-stone is applied, are various; it is principally employed as a building stone, and burnt for making lime and mortar; nor is it less important to the agriculturist as a manure, to the miner as a flux, for the reduction of ores, to the soap-boiler, to the tanner, &c. It is a substance very abundantly diffused throughout the globe.

It is from compact lime-stone, that lime, so extensively used in the arts, is chiefly obtained; pure white marble, or lime-stone, undoubtedly furnishes the best lime, though but little superior to that obtained from gray, compact lime-stone.

SECTION VII.——The Burning of Lime.

This is a process by which lime-stone, marble, shells, &c., are converted into lime, by means of heat, in kilns properly constructed for the purpose. By the application of heat, to any of these substances, their carbonic acid is driven off, and leaves the lime in a powder.

The calcination of lime-stone may be effected by wood, coal, or peat, as fuel; but the heat should not much exceed a red heat, unless the stone employed be nearly a pure carbonate. The fuel is placed in layers, alternately with those of the stones, or calcareous materials in the kilns, and the process of burning continued for any length of time, by repeated applications of fuel and the calcareous materials at the top; the lime being drawn out occasionally from below, as it is burnt.

Fossil, or mineral coal, are supposed to be the most convenient and suitable materials for effecting this business, where they can be procured plentifully, and at a sufficiently cheap rate; as they burn the stone, or other calcareous matter more perfectly, and, of course, leave fewer cores in the calcined pieces, than when other sorts of fuel are employed for the purpose.

Peat, also, is highly recommended for its cheapness and uniformity of heat. When coal is used, the lime-stones are liable, from excessive heat, to run into solid lumps; which may be avoided by the use of peat, as it keeps them in an open state, and admits the air freely.

Count Rumford, with his usual attention to economy in fuel, and in the expense of caloric, has invented an oven for preparing lime. It has the form of a high cylinder with a hearth at the side, and at some distance above the base. The combustible is placed on the hearth, and burns with an inverted or reflected flame. The lime is taken out at the bottom, while fresh additions of lime-stone are made at the top; and thus the oven is preserved constantly hot.

Lime-stone recently dug, and of course moist, calcines more easily than that which has become dry by exposure to the air: in the latter case it is found convenient even to moisten the stone, before putting it into the kiln.

Lime-stone loses about four-ninths of its weight by burning; but is nearly of the same bulk.

Lime thus obtained, is called quick-lime. If it be wet with water, it instantly swells and cracks, becomes exceedingly hot, and at length falls into a white, soft, impalpable powder. This process is denominated the slaking of lime. The compound formed is called the hydrate of lime, and consists of about three parts of lime to one of water. When intended for mortar, it should immediately be incorporated with sand, and used without delay, before it imbibes carbonic acid anew from the atmosphere. Lime doubles its bulk by slaking.

SECTION VIII.——Common Mortar and Cement.

These are the substances generally made use of, for the uniting medium between bricks, or stones, in forming them into buildings. Though many experiments have been made to ascertain the best materials for these compounds, and the mode of mixing them, and not without a degree of success, still, much yet seems to remain to be discovered. A composition of lime, sand and water, in consequence of the facility, with which they pass from a soft state to a stony hardness, has, in common uses, superseded all other ingredients. But in order that the mortar should be of a good quality, great care and skill are requisite, in the selection of the materials, and the proportioning of them; and much depends on the degree of labor bestowed on the mixing and incorporation. The lime should be well burnt, and free from fixed air and carbonic acid. Hence, lime that has become effete from exposure to the atmosphere, is impaired in its quality. The sand most proper for mortar is that which is wholly siliceous, and which is sharp, that is, not having its particles rounded by attrition. Fresh sand is to be preferred to that, taken from the vicinity of the sea-shore, the salt of which is liable to deliquesce and weaken the strength of the mortar: it

should be clean, rather coarse, and free from dirt and all perishable ingredients. The water should be pure, fresh, and, if possible, free from fixed air.

The proportions of lime and sand to each other, are varied in different places; the amount of sand, however, always exceeds that of lime. The more sand that can be incorporated with the lime, the better, provided the necessary degree of plasticity is preserved; for the mortar becomes stronger, and it also sets, or consolidates more quickly, when the lime and water are less in quantity and more subdivided. From two to four parts of sand are commonly used to one of lime, according to the quality of the lime, and the labor bestowed upon it. The more pure the lime is, and the more thoroughly it is beaten, or worked over, the more sand it will take up, and the more firm and durable does it become.

SECTION IX.

The ancient masons were so very scrupulous in the process of mixing their mortar, that it is said the Greeks kept ten men constantly employed for a long space of time, to each bason; this rendered their mortar of such prodigious hardness, that Vetruvius tells us, the pieces of plaster falling off from old walls, served to make tables.

It was a maxim among the old masons to their laborers, that they should dilute the mortar with the sweat of their brows, that is, labor a long time, instead of drowning it with water to have it done the sooner.

The weakness of modern mortar, compared to the ancient, is a common subject of regret; and many ingenious men take it for granted, that the process used by the Roman architects in preparing their mortar, is one of those arts which is now lost, and have employed themselves in making experiments for its recovery.

But the characteristics of all modern artists, builders among the rest, seems to be, to spare their time and labor as much as possible, and to increase the quantity of the article they produce, without much regard to goodness; and perhaps there is no manufacture, in which it is so remarkably exemplified, as in the preparation of common mortar.

SECTION X.

Mr. Doffie gives the following method of making mortar impenetrable to moisture, acquiring great hardness, and exceedingly durable, which was discovered by a gentleman of Neufchatel. Take of unslacked lime, and of fine sand, in the proportion of one part of lime to three of sand, as much as a laborer can well manage at once; and then, adding water gradually, mix the whole well together with

a trowel, till it be rendered to the consistency of mortar. Apply it immediately, while it is hot, to the purpose, either of mortar, as a cement to brick or stone, or of plaster, to the surface of any building. It will then ferment for some days in drier places, and afterwards gradually concrete, or set, and become hard; but in a moist place, it will continue soft for three weeks, or more; though it will at length obtain a firm consistence, even if water have such access to it as to keep the surface wet the whole time. After this it will acquire a stone-like hardness, and resist all moisture. The perfection of this mortar depends on the ingredients being thoroughly blended together; and the mixture being applied immediately after, to the place where it is wanted. The lime for this mortar must be made of hard lime-stone, shells or marl; and the stronger it is, the better the mortar will be. When a very great hardness and firmness are requisite in this mortar, the using of skimmed milk, instead of water, either wholly or in part, will produce the desired effect.

SECTION XI.——Monsieur Loriat's Mortar.

Monsieur Loriat's Mortar,—The method of making which, was announced by order of his majesty, at Paris, in 1774: it is made in the following manner:—Take one part of brick dust, finely sifted, two parts of fine river sand, screened, and as much old slaked lime as may be sufficient to form mortar with water, in the usual method, but so wet as to serve for the slaking of as much powdered quick-lime as amounts to one fourth of the whole quantity of brick-dust and sand. When the materials are well mixed, employ the composition quickly, as the least delay may render the application imperfect, or impossible. Another method of making this compound is, to make a mixture of the dry materials; that is, of the sand, brick-dust, and powdered quick-lime, in the prescribed proportion; which mixture may be put into sacks, each containing a quantity sufficient for one or two troughs of mortar. The above mentioned old slaked lime and water being prepared apart, the mixture is to be made in the manner of plaster, at the instant when it is wanted, and is to be well chafed with the trowel.

SECTION XII.

Dr. Higgins has made a variety of experiments, in consequence of the modern discoveries relating to fixed air, for the purpose of improving the mortar used in buildings. According to this author, the perfection of lime, prepared for the purpose of making mortar, consists cheifly in its being totally deprived of its fixed air. And as lime very quickly imbibes fixed air, when exposed to the atmosphere, it should be applied to use as soon as possible after it is prepared.

From the experiments of the same author, made with a view to ascertain the best relative proportions of lime, sand, and water, in the making of mortar, it appeared that those specimens were the best, which contained one part of lime in seven of sand; for those which contained less lime, and were too short while fresh, were more easily cut and broken, and were pervious to water; and those which contained more lime, although they were closer in grain, did not harden so soon, or to so great a degree, even when they escaped cracking by lying in the shade to dry slowly.

Dr. Higgins has also shown, that though the setting of mortar, as it is called, is chiefly owing to its drying, yet its induration, or its acquiring a stony hardness, is not caused by its drying, as has been supposed, but depends principally on its acquiring carbonic acid, or fixed air, from the atmosphere. In order to the greatest induration of mortar, therefore, it must be suffered to dry gently, and set; the drying must be effected by temperate air, and not accelerated by the heat of the sun, or fire. It must not be wet soon after it sets; and afterwards, it ought to be protected from wet as much as possible, until it is completely indurated. The same author describes a cement, or stucco, of his own invention, for incrustations, external and internal, of very great hardness, for which he obtained letters patent. As for the materials of which it is made, drift sand, or quarry sand, consisting chiefly of hard quartose flat-faced grains, with sharp angles, free from clay, salts, &c. is to be preferred. The sand is to be sifted in streaming clear water, through a sieve which shall give passage to all such grains as do not exceed one sixteenth of an inch in diameter; and the stream of water, and sifting, are to be so regulated, that all the finer sand, together with clay and other matter lighter than sand, may be washed away with the stream. While the purer and coarser sand, which passes through the sieve, subsides in a convenient receptacle, the coarse rubbish in the sieve is to be rejected. The subsiding sand is then washed in clean streaming water, through a finer sieve, so as to farther cleanse it, and sorted into two parcels,—a coarser, which will remain in the sieve, which is to give passage only to such grains as are less than one thirteenth of an inch in diameter, and which is to be kept apart under the name of coarse sand; and a finer, which will pass through the sieve, and subside in the water, and which is to be saved apart under the name of fine sand. These are to be dried separately, either in the sun, or on a clean iron plate set on a convenient surface, in the manner of a sand heat. The lime to be chosen, should be stone-lime, which heats the most in slaking, and slakes the quickest when duly watered; which is the freshest made, and most closely kept. Let this lime be put into a brass-wired, fine sieve, to the quantity of fourteen pounds. Let the lime be slaked by plunging it in a butt, filled with soft water, and raising it out quickly, and suffering it to heat and fume, and by repeating this plunging, and raising alternately, and agitating the lime, until it be made to pass through the sieve. Reject the part of the lime that does not easily pass through the sieve, and use fresh portions of lime, till as many ounces have passed through the sieve as there are quarts of water in

the butt. Let the water thus impregnated, stand in the butt, close covered, until it becomes clear; and through wooden cocks, placed at different heights in the butt, draw off the clear liquor, as fast and as low as the lime subsides, for use. This clear liquor is called the cementing liquor.

Let fifty-six pounds of the aforesaid chosen lime be slaked, by gradually sprinkling on it the cementing liquor, in a close, clean place. Let the slaked part be immediately sifted through the fine brass-wired sieve. Let the lime which passes be used instantly, or kept in air-tight vessels, and let the part of the lime which does not pass through the sieve be rejected; the other part is called purified lime.

Let bone-ashes be prepared in the usual manner, by grinding the whitest burnt bones; but they should be finely sifted.

Having thus prepared the materials, take fifty-six pounds of the coarse sand, and forty-two pounds of the fine sand; mix them on a large plank of hard wood, placed horizontally. Then spread the sand so that it may stand at the height of six inches, with a flat surface on the plank; wet it with the cementing liquor; to the wetted sand add fourteen pounds of the purified lime, in several successive portions, mixing and beating them together; then add fourteen pounds of the bone ashes in successive portions, mixing and beating them all together. This, Dr. Higgins calls the water cement, coarse grained, which is to be applied in building, pointing, plastering, stuccoing, &c. Observing to work it expeditiously in all cases, and in stuccoing, to lay it on by sliding the trowel upwards upon it; to well wet the materials used with it, or the ground on which it is laid, with the cementing liquor, at the time of laying it on; and to use the cementing liquor for moistening the cement and facilitating the floating of it.

A cement of a finer texture may be made, by using ninety pounds of the fine sand, and fifteen pounds of lime, with bone-ashes and cementing liquor. This is called water cement, fine grained; and is used in giving the last coating or finish to any work, intended to imitate the finer grained stones or stucco.

For a cheaper or coarser cement, take of coarse sand, fifty-six pounds, of the foregoing coarse sand, twenty-eight pounds, and of the finer sand, fourteen pounds; and after mixing and wetting these with the cementing liquor, add fourteen pounds of the purified lime, and then as much bone-ashes, mixing them together. The water cement above described, is applicable to forming artificial stone; by making alternate layers of the cement and of flint, hard stone, or brick, in moulds of the figure of the intended stone, and by exposing the masses so formed to the open air to harden. When the cement is required for water fences, two thirds of the bone-ashes, are to be omitted, and in their stead, an equal measure of powdered terras (*see Terras*,) is to be used. When the cement is required of the finest grain, or in a fluid form, so that it may be applied with a brush, flint powder, or the powder of any quartose, or hard earthy substance, may be used in the place of sand, so that the pow-

der shall not be more than six times the weight of the lime, nor less than four times its weight. For inside work the admixture of hair with the cement is useful.

When a fragment of a worked stone, is by accident, or otherwise, broken off, it may be united, with a firmness sufficient to resist a considerable degree of force, by a cement made of 5 parts of *gum shelac*, and 1 part of *Burgundy pitch*, incorporated together, in an iron vessel, over a slow fire. The cement, while hot, should be applied to the stone, raised, also, to a moderate degree of heat. In order that the cement should not cool too rapidly, a piece of iron should be heated, and laid on the stone, and the whole suffered to cool gradually together. The cement may be made to assume the color of the stone to be united, by mixing with it a portion of the stone itself, reduced to a fine powder. Stones, thus united, may afterwards be smoothed, by gentle hammering, while the fracture is not perceptible, except by very close examination.

SECTION XIII.

Although a well made mortar, composed merely of sand and lime, allowed to dry, becomes impervious to water, so as to serve for the lining of reservoirs and aqueducts; yet if the circumstances of the building are such as to render it impracticable to keep out the water, whether fresh or salt, a sufficient length of time, the use of common mortar must be abandoned.

Among the nations of antiquity, the Romans appear to have been the only people, who have practised building in water, and especially in the sea, to any extent. The bays of Baiae, of Pozzuoli and of Cumae, from their coolness and salubrity of situation, were the fashionable resorts of the wealthier Romans, during the summer months; who not only erected their villas and baths as near the shore as possible, but constructed moles, and formed small islands, in the more sheltered parts of these bays; on which, for the sake of the grateful coolness, they built their summer houses and pavilions. They were enabled to build thus securely, by the discovery, at the town of Puteoli, of an earthy substance, which was called *pulvis puteolanus*, Puteolan powder, or as it is now called, puzzolana, (*which see*). The only preparation, which this substance undergoes, is that of pounding and sifting, by which it is reduced to a coarse powder; in this state, being thoroughly beaten up with lime, either with or without sand, it forms a mass of remarkable tenacity, which speedily sets, under water, and becomes, at least, as hard as good free-stone.

Limes, which contain a portion of clay, or argillaceous matter, have also the property of forming a mortar, which hardens under water. A composition, formed of two bushels of clayey lime, one bushel of puzzolana, and three of clean sand, the whole being well beaten together, make a good water cement.

The Terras, which is so much used in Holland, is a preparation of a species of basalt, (*which see,*) by calcination. It possesses the property, when mixed with lime, of forming a water cement, not inferior to puzzolana. Perhaps common green-stone and other substances may be found to answer the same purposes.

The materials of terras mortar, generally used in the construction of the best water work, are one measure of quick-lime, or two measures of slaked lime, in the dry powder, mixed with one measure of terras, well beaten together to the consistency of paste, using as little water as possible.

Another kind, almost equally good, and considerably cheaper, is made of two measures of slaked lime, one of terras, and three of coarse sand; it requires to be beaten longer than the foregoing, and produces three measures and a half of excellent mortar. When the building is constructed of rough, irregular stones, where cavities and large joints are to be filled up with cement, the pebble, or coarse sand mortar, may be most advantageously applied; this was a favorite mode of constructing among the Romans, and has been much used since. Pebble mortar will be found of a sufficient compactness, if composed of two measures of slaked, argillaceous lime, half a measure of terras, or puzzolana, and one measure of coarse sand, one of fine sand, and four of small pebbles, screened and washed. It is only under water, that the terras mortar sets well.

The scales produced by hammering red-hot iron, which may be procured at the forges and blacksmith's shops, have been long known as an excellent material in water cements. The scales being pulverized and sifted, and incorporated with lime, are found to produce a cement equally powerful with puzzolana mortar, if employed in the same quantity.

Fresh made mortar, if kept under ground, in considerable masses, may be preserved for a great length of time, and the older it is before it is used, the better it has been thought to be.

Pliny imforms us, that the ancient Roman laws prohibited builders from using mortar that was less than three years old; and a similar law prevails in Vienna.

SECTION XIV.——Stucco.

This is a composition of white marble, pulverized, and mixed with plaster, or lime; the whole sifted and wrought up with water; to be used like common plaster.

Of this are made statues, busts, basso-relievos and other ornaments of architecture.

A stucco, for walls, &c. may be formed of the grout, or putty, made of good stone-lime, or the lime of cockle shells, which is better, properly tempered and sufficiently beat, mixed with sharp grit sand, in a proportion which depends on the strength of the lime. Drift-sand is best for this purpose, and it will derive advantage from

being dried on an iron plate or kiln, so as not to burn, thus the mortar would be discolored. When this is properly compounded, it should be put in small parcels against walls, or otherwise to mellow, as the workmen term it; reduced again to soft putty, or paste, and spread thin on the walls without any under coat, and well trowelled. A succeeding coat should be laid on, before the first is quite dry, which will prevent points of brick work appearing through it. Much depends on the workman giving sufficient labor, and trowelling it down. If this stucco, when dry, be laid over with boiling linseed oil, it will last a long time, and not be liable, when once hardened, to the accidents to which common stucco is liable.

SECTION XV.

Adam's Oil Cement, or Stucco, is prepared in the following manner. For the first coat, take twenty-one pounds of fine whiting, or oyster-shells, or any other sea-shells calcined, or plaster of Paris, or any calcareous material calcined and pounded, or any absorbent materials whatever, proper for the purpose; add white or red lead at pleasure; deducting from the other absorbent materials in proportion to the white or red lead added; to which put four quarts, beer measure, of oil; and mix them together with a grinding-mill or any levigating machine. And afterwards mix, and beat up the same well with twenty-eight pounds, beer measure, of any sand or gravel, or of both, mixed and sifted, or of marble or stone pounded, or of brick dust, or of any kind of metallic, or mineral powders, or of any solid material whatever, fit for the purpose.

For the second coat, take sixteen pounds and a half of superfine whiting, or oyster-shells, or any sea-shells calcined, &c., as for the first coat; add sixteen pounds and a half of white or red lead, to which put six quarts and a half of oil, wine measure, and mix them together as before. Afterwards mix and beat up the same well with thirty quarts, wine measure, of fine sand or gravel, sifted, or stone, or marble pounded, or pyrites, or any kind of metallic or mineral powder, &c. This composition requires a greater proportion of sand, gravel or other solids, according to the nature of the work, or the uses to which it is to be applied. If it be required to have the composition colored, add to the above ingredients such a portion of painters' colors as will be necessary to give the tint or color required. In making the composition, the best linseed, or hemp seed, or other oils, proper for the purpose, are to be used, boiled or raw, with drying ingredients, as the nature of the work, the season, or the climate requires; and, in some cases, bees-wax may be substituted in place of oil. All the absorbent and solid materials must be kiln dried. If the composition is not to be any other color than white, the lead may be omitted, by taking the full proportion of the other absorbents; and also white or red lead may be substituted alone, instead of any absorbent material.

The first coat of this composition is to be laid on with a trowel, and floated to an even surface, with a rule or handle float. The second coat, after it is laid on with a trowel, when the other is nearly dry, should be worked down and smoothed, with floats edged with horn, or any hard, smooth substance, that does not stain. It may be proper, previously to laying on the composition, to moisten the surface on which it is to be laid, by a brush, with the same kind of oil or ingredients, which pass through the levigating machine, reduced to a more liquid state, in order to make the composition adhere the better. This composition admits of being modelled, or cast in moulds, in the same manner as plasterers, or statuaries model or cast their stucco-work. It also admits of being painted upon, and adorned with landscape, or ornamental, or figure painting, as well as plain painting.

CHAPTER III.

PRACTICAL GEOMETRY, ADAPTED TO MASONRY AND STONE-CUTTING.

SECTION I.

ON THE POSITION OF LINES AND POINTS.

As the construction of every complex object in nature consists of certain combinations of the simple operations of geometry; and as positions cannot be understood without angles and parallel lines, it will be necessary to treat of the practical part of this science, at least as far as the operations of the positions of lines and points are concerned, in order to render the construction and the language of geometry familiar to the student in their applications to the principles of Masonry.

PROBLEM I.

From a given point in a given straight line to draw a perpendicular.

Plate 1. Let AB, *fig.* 1. be a given straight line, and *c* the given point. In AB take two equal distances, *cd* and *ce*. From *d* as a centre, with any radius greater than *cd* or *ce*, describe an arc at *f*, and with the same radius, from the point *e*, describe another arc intersecting the former at *f*, and draw *fc*, and *fc* is the perpendicular required.

PROBLEM II.

From the one extremity of a straight line to draw a perpendicular.

Fig. 2. Let AB be the given straight line, and let it be required to draw a perpendicular from the extremity B. On one side of the line AB take any convenient point *c*; and from *c*, as a centre, with any radius that will cut the line, describe an arc *d* Be, intersecting AB in the point *d*; through *c* draw the diameter *de*, and join *e*B, and *e*B is the perpendicular required.

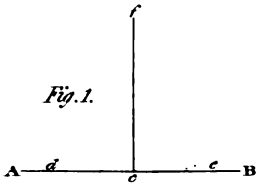


Fig. 1.

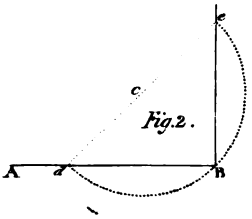


Fig. 2.

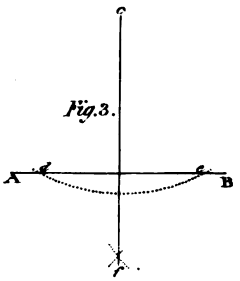


Fig. 3.

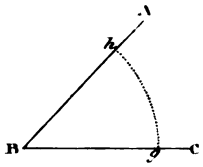
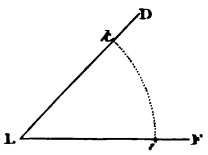


Fig. 4.



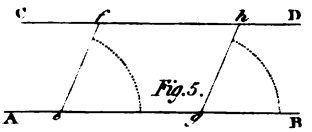


Fig. 5.

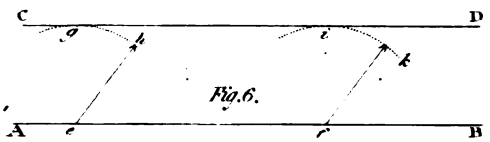


Fig. 6.

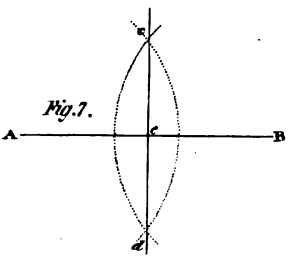
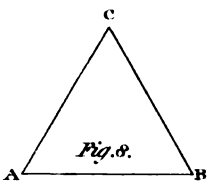


Fig. 7.



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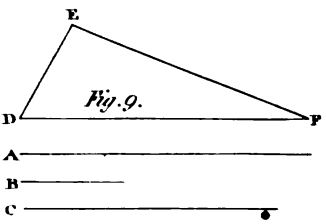

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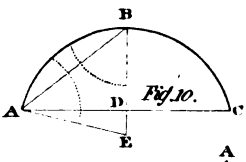

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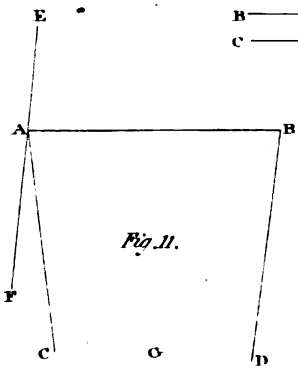

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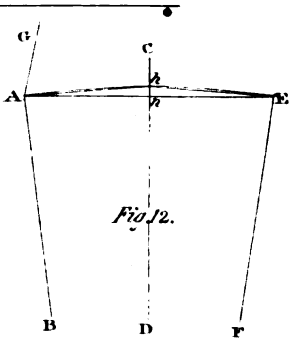

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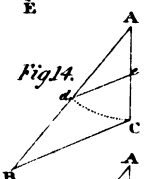

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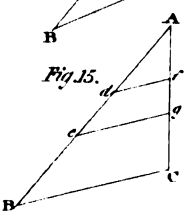

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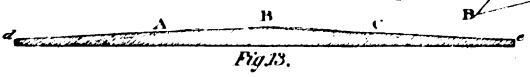

Fig. 13.

PROBLEM III.

From a given point out of a straight line to let fall a perpendicular.

Fig. 3. Let AB be the given straight line, and *c* the given point; it is required to draw a straight line from *c*, perpendicular to AB. From *c*, as a centre, with any distance that will cut the line AB, describe an arc intersecting AB in the points *d* and *e*; from *d*, as a centre, with any radius greater than the half of *de*, describe an arc, and from *e*, with the same radius, describe another arc intersecting the former in *f*, and draw *fc*, and *fc* is the perpendicular required.

The criterion of the truth of the method of *fig.* 2, is that of the angle in a semicircle being a right angle.

PROBLEM IV.

At a given point in a given straight line, to make an angle equal to a given angle.

Fig. 4. Let CBA be the given angle, and LF the given straight line. Let it be required to draw a straight line, at the point L, to make an angle with the line LF, equal to the angle CBA. From the point B, with any radius, describe an arc meeting BA in *h*, and BC in *g*; and from the point L, with the same radius, describe an arc *ik*, meeting LF in *i*. Make *ik* equal to *gh*, and through *k* draw the straight line LD, and FLD is the angle required.

PROBLEM V.

Through a given point *f* to draw a straight line parallel to a given straight line AB.

Fig. 5. Let *f* be the given point, and AB the given straight line. Draw any straight line *fe*. meeting AB in *e*, and draw *gh*, making the angle *hg*B equal to *fe*B, Make *gh* equal to *ef*. Through the points *f* and *h* draw the line CD, and CD is parallel to AB, as required.

PROBLEM VI.

To draw a straight line parallel to a given straight line at a given distance from the given straight line.

Fig. 6. Let AB be the given straight line; it is required to draw a straight line at a given distance from BC. In AB take any two points *e* and *f*; from *e*, with the given distance, describe an arc *gh*; and from *f*, with the same distance, describe another arc *ik*. Draw the line CD to touch the arcs *gh* and *ik*, and CD is parallel to AB, as required.

PROBLEM VII.

To bisect a given straight line AB by a perpendicular.

Fig. 7. From the point A as a centre, with any radius greater than the half of AB, describe an arc *cd*; and from B, with the same radius, describe another arc intersecting the former at *c* and *d*, and draw *cd*, intersecting AB in *e*; then AB is divided in *e*, as required.

PROBLEM VIII.

Upon a given straight line to describe an equilateral triangle.

Fig. 8. Let AB be the given straight line. From the point A, with the ra-

dius AB, describe an arc, and from the point B, with the radius BA, describe another arc, intersecting the former in C, and draw the straight lines CA and CB; then ABC is the equilateral triangle required.

PROBLEM IX.

Upon a given straight line to describe a triangle, of which the sides shall be equal to three given straight lines, provided that any one of the three given lines be less than the sum of the other two.

Fig. 9. Let the three given straight lines be A, B, C, and let DF be the straight line on which the triangle is required to be described. Make DF equal to the given straight line A. From D, with the radius of the line B, describe an arc, and from F, with the radius of the line C, describe another arc, meeting the arc described from D in the point E. Draw ED and EF, then DEF is the triangle required.

PROBLEM X.

Given the base and height of the segment of a circle to find the centre of the circle, and thence to describe the arc.

Fig. 10. Let AC be the base, bisect AC in D by the perpendicular BE; make DB equal to the height, and join the points A and B. Make the angle BAE equal to ABE, and the point E is the centre required.

From the point E, with the radius EA or EB, describe the arc ABC; then ABC is the arc required.

N. B. The centre must also have been found by bisecting AB by a perpendicular, which would have met BE in the point E.

PROBLEM XI.

Given two converging lines, through a given point in one of them, to draw a third straight line, so that the angles on the same side of the line thus drawn, made by this line and each of the first two given lines, may be equal to each other.

Fig. 11. Let the two converging lines be AC and BD, and let A be the given point. Draw AE parallel to BD; bisect the angle CAE by the straight line AB; then will the angles CAB and DBA be equal to one another.

For, suppose AE to be produced from A to F, and suppose AC and BD to be produced to meet in some point G, then AC would have been a line falling upon the two parallel straight lines AF and BD, and consequently making the angle at G equal to the angle FAC; and since the three angles of every triangle are equal to two right angles, and since the angles FAC, CAB, BAE, are also equal to two right angles, and since FAC is equal to the vertical angle of the triangle, the angle CAE is equal to the sum of the angles at the base; and therefore, since CAB is half the sum, the angle ABD must be equal to the other half.

PROBLEM XII.

Given two converging lines, to describe the arc of a circle through a given point in one of them, without having recourse to a centre, so that the point of convergency may be in the centre of the arc.

Fig. 12. Let AB and EF be the two converging lines, and A the given point through which the arc is to pass. Draw AE, making the angles BAE and FEA

Fig. 1.

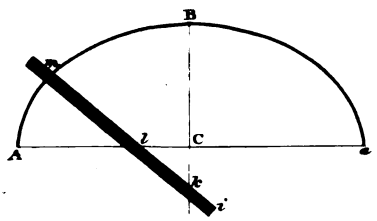
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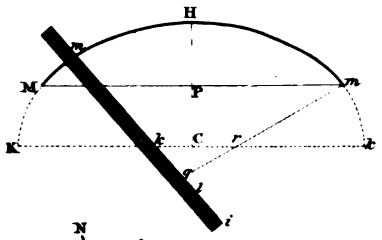
Fig. 2.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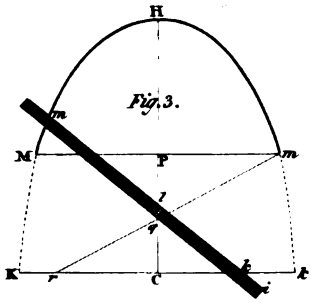
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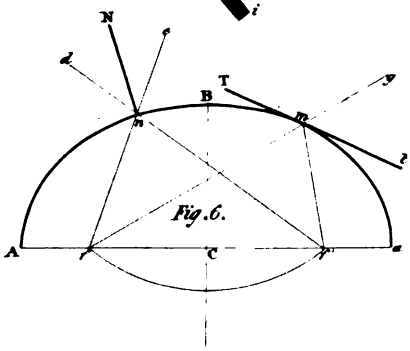
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Fig. 6.
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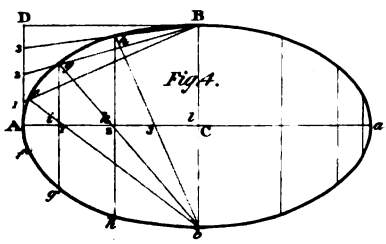
D
B
Fig. 4.
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C
a

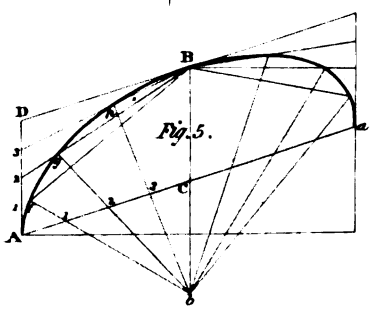
B
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Fig. 5.
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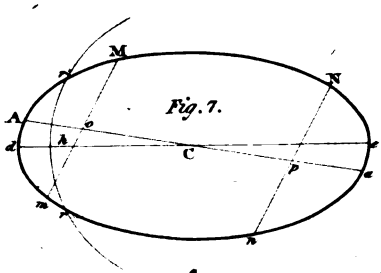
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Fig. 7.
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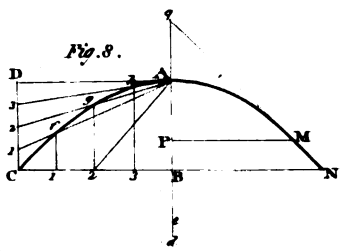
Fig. 8.
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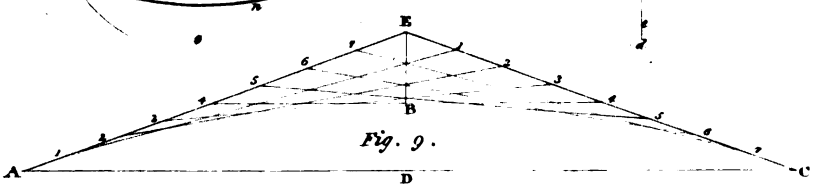
E
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Fig. 9.
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D
C

equal to each other. Bisect AE by the perpendicular CD, and draw A*h*, making the angles BA*h* and D*h*A equal to one another; then A*h* is the chord of the arc, and *nh* is the versed sine. Suppose now that the three points A, *h*, E, are transferred to A, B, C, *fig.* 13. Join BA and BC. Produce BA to *d*, and BC to *e*. Make the edge of a slip of wood to the angle *d*B*e*. Move the edge *d*B*e* of the slip of wood so that the point B may be upon A ; then move this slip again, so that while the part B*d* of the edge of the slip is sliding upon the pin at A, and the part B*e* upon the pin at C, a pencil held to the angle B, will describe a curve ; then this curve will be the arc required.

PROBLEM XIII.

Given two straight lines to find a third porportional.

Fig. 14. From any point A, draw any two straight lines BA, AC, at any angle. Make AB, equal to one of the given straight lines, and AC equal to the other; and in AB make A*d* equal to AC. Join BC and draw *de* parallel to BC, meeting AC in *e* ; then A*e* is the third proportional required.

Or if A*e* be equal to one of the given straight lines, and A*d* equal to the other. Make AC equal to A*d*. Join *de* and draw CB parallel to *ed*, then AB is the third proportional.

PROBLEM XIV.

Given a straight line, and how divided, to divide another in the same proportion.

Fig. 15. Draw the lines BA, AC as in the preceding problem, and let AB be the given divided line, *d* and *e* being the points of division, and let AC be the line to be divided. Join BC and draw *eg* and *df* parallel to BC, meeting AC in *f* and *g* ; then AC is divided in *f* and *g*, in the same proportion as AB is divided in the points *d* and *e*.

PROBLEM XV.

Given three straight lines to find a fourth proportional.

Fig. 15. The angle BAC being made as before; let A*e* be equal to one of the given lines, A*d* equal to a second, and *af* equal to the third. Join *df* and draw *eg* parallel to *df* ; then A*g* is the fourth proportional.

SECTION II.

ON THE SPECIES, NATURE, AND CONSTRUCTION OF CURVE LINES.

The geometrial orders of lines employed in architecture in the construction of arches, are circular and elliptic, and occasionally parabolic, hyperbolic, cycloidal, and catenarian curves.

In houses, the chief lines employed in the construction of arches and vaults, are circular and elliptic curves, generally a semi, and sometimes less, but seldom or never greater. When a circular or elliptic arc is adopted, one of the axes of the curve is most frequently

situated upon the springing line; but is sometimes placed so as to be parallel to it. The most usual portions of circular or elliptic curves are the semi; and in the pointed style of architecture, parabolic and hyperbolic curves are very frequently employed.

In bridge building, besides circular and elliptic curves which are the most often used in the construction of stone arches, cycloidal curves may also be introduced. In chain bridges, or bridges of suspension, not only the circular and parabolic curves, but that of the catenarian may be employed. The suspending chains necessarily assume the form of catenarian curves; but the road-way may be any curve line whatever; but as all curves are nearly circular at the vertex, it will be better to employ those in the construction of works which are susceptible of the most easy calculation.

Among the numerous orders of curve lines, the parabolic affords the most easy means of computing its ordinates and tangents, which will be found necessary in ascertaining the rise and inclination of the road-way in all points of the curve, from either extreme to the centre of the bridge.

The base of an arc is that upon which the arc is supposed to stand; and the highest point of an arc is that in which a straight line parallel to the base would meet the curve, without the possibility of coming within the area included by the curve and its base, and this point is called the summit of the arc.

As the curves employed in building are generally symmetrical, therefore they are equal and similar on each side of the summit, and their areas are equal and similar on each side of the perpendicular from the middle of the base.

PROBLEM I.

To describe a semi-ellipse upon the transverse axis.

Plate II. Let A*a*, *fig.* 1, be the axis major, and let BC bisecting A*a* perpendicularly in the point C, be the semi-conjugate axis.

Upon the straight edge *mi* of a rule, mark the point *m* at or near one of its ends, and the point *l* at a distance; from *m* equal to BC, the semi-conjugate axis; and the point *k* at a distance from *m*, equal to AC or C*a* the semi-transverse axis; the distance *kl* being equal to the difference of the two axes. To find any point in the curve, place the point *k* in the line BC produced, and the point *l* in the axis A*a*; and mark the paper or plane on which the figure is to be described at the point *m*. Proceed in this manner until a sufficient number of points are found, and draw a curve through them, and the curve will be the semi-ellipse required.

PROBLEM II.

Upon a given double ordinate to describe the segment of an ellipse, to a given abscissa, and to a given semi-axis in that abscissa.

Fig. 2 and 3. Let M*m* be the double ordinate, PH the abscissa, and HC the semi-axis.

Through the centre C, draw K*k* parallel to M*m*. From either extremity *m* of the double ordinate as a centre with the distance HC of the given semi-axis, as radius describe an arc intersecting K*k* in *r*. Draw *mr* intersecting HC in *q*, or produce

mr and HC to meet in *q*; then *mq*, *fig.* 2, will be the semi-transverse, and *mr* the semi-conjugate, and in *fig.* 3 the contrary will take place, *mr* will be the semi-transverse, and *mq* the semi-conjugate; the two axes being thus found, the curve may be described as in the immediately preceding problem.

PROBLEM III.

Given two conjugate diameters to find any number of points in the curve, and thence to describe it.

Figs. 4 and 5. Let A*a*, B*b*, be the conjugate diameters. Draw AD parallel to BC, and BD parallel to CA. Divide AD and AC each into the same number of equal parts. Through the points of division in AC draw straight lines from *b*, and through the points of division in AD draw other straight lines to the point B, meeting those drawn from *b* in the points *f*, *g*, *h*. Draw a curve line through the points A, *f*, *g*, *h*, B, which will be one quarter of the whole figure. The other three will of course be found in the same manner.

PROBLEM IV.

To draw a normal, or line perpendicular to the curve of an ellipse at a given point in the curve.

Fig. 6. Let the curve be AB*a*, and let A*a* be the transverse axis, and CB the semi-conjugate, and let it be required to draw a line from the point *n* perpendicular to the curve. With AC the semi-axis major as a radius; from the point B describe an arc, intersecting A*a* in the foci, *f*, *f'*. From the points *f*, *f'*, and through the point *n*, draw *f' d* and *fe*, and bisect the angle *e n d*, and the bisecting line *n*N will be perpendicular to the curve as required.

PROBLEM V.

To draw a tangent to the curve of an ellipse at a given point.

Fig. 6. Let *m* be the given point. Draw *fm*, and produce *fm* to *g*, and join the points *f'*, *m*. Bisect the angle *f' mg*, and the bisecting line T*t* will be the tangent required.

PROBLEM VI.

The curve of an ellipse being given, to find the two axes.

Fig. 7. Let AMN*nm* be the given curve within the figure; draw any two parallel lines M*m*, N*n*. Bisect M*m* in *o*, and N*n* in *p*, and draw the straight line A*opa*. Bisect A*a* in C, from C as a centre, with any radius that will cut the curve; describe the arc *rr'*, intersecting the curve in the points *rr'*, and draw the straight line *rr'*. Bisect *rr'* in *h*, and through the points *h* and C draw the line *de*, then *de* is the axis major; and a line drawn through the point C at right angles to *de*, to meet the curve on each side of C will be the axis minor.

PROBLEM VII.

With a given abscissa and ordinate, to describe a parabola.

Fig. 8. Let AB be the abscissa, and BC the ordinate. Draw CD parallel to BA, and AD parallel to BC. Divide CD and CB each into the same number of equal parts. From the points 1, 2, 3 in CD draw lines to A, and from the points 1, 2, 3 in CB, draw lines parallel to BA, meeting the former lines to A in the

points *f*, *g*, *h*. Draw the curve C*fgh*A, which will be one half of the parabola, the other half will be found in the same manner. The radius of curvature at the point A, is half the parameter.

PROBLEM VIII.

The curve of a parabola being given, to find the parameter.

Fig. 8. Let CAN be the curve of the parabola. Bisect BC in the point 2, and draw A2 and 2*d* perpendicular to A2, meeting AB produced in *d*; then B*d* is one fourth part of the parameter.

For AB : B2 :: B2 : B*d*, now let AB=*a*, BC=*b*, then B2=$\frac{1}{2}b$, hence *a* : $\frac{1}{2}b$ :: $\frac{1}{2}b$: $\frac{1}{4}p$; whence $ap=b^2$ or $p=\frac{b^2}{a}$.

PROBLEM IX.

To draw a tangent to any point M, in the curve of a parabola.

Fig. 8. Draw the ordinate PM, and produce PA to *q*. Make A *q* equal to AP, and draw the straight line *q* M; then *q* M will be the tangent required.

For the subtangent of the curve is double to the abscissa.

PROBLEM X.

To form the curve of a parabola by means of tangents.

Fig. 9. Let AC be the double ordinate. Draw DB bisecting AC, and make DB equal to the abscissa. Produce DB to E, and make BE equal to BD. Draw the two straight lines EA and EC. Divide AE and EC each in the same proportion, or into the same number of equal parts at the points 1, 2, 3, &c. in each line. Draw the straight lines 1-1, 2-2, 3-3, &c. and their intersections will circumscribe the curve of the parabola as required.

Scholium. Small portions of the curves of conic sections, near to the vertices, may be described with compasses so as not to be perceptible; and thus, not only in the parabola, but in the ellipse; and in the hyperbola, the radius of curvature at the vertices is half the parameter, which passes through the focus. In the parabola, the parameter is a third proportional to the abscissa and ordinate; and in the ellipse, and hyperbola, the parameter is a third proportional to the transverse and conjugate axis; and therefore may be easily found by lines or by calculation on large works, such as bridges, &c.

Fig. 1.

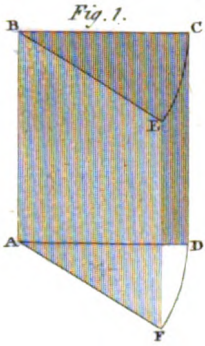
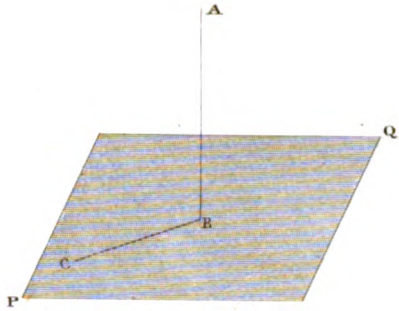


Fig. 2.



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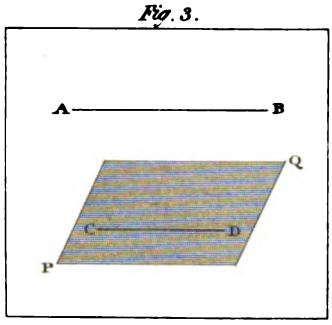

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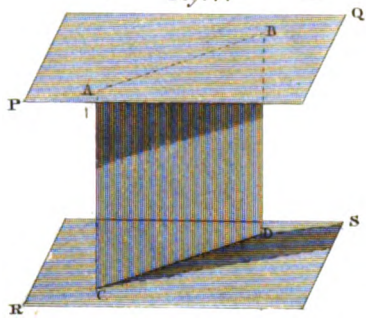


Fig. 5.

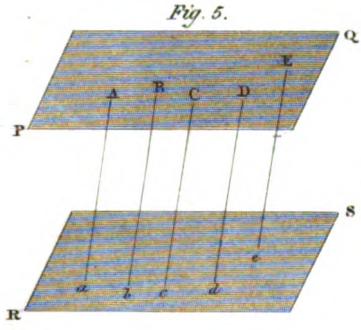
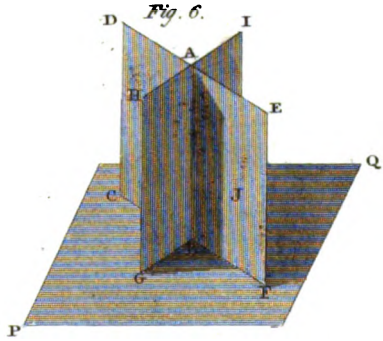


Fig. 6.



SECTION III.

OF THE POSITION OF LINES AND PLANES, AND THE PROPERTIES ARISING FROM THEIR INTERSECTIONS.

A plane is a surface in which a straight line may coincide in all directions.

A straight line is in a plane, when it has two points in common with that plane.

Two straight lines which cut each other in space, or would intersect, if produced, are in the same plane; and two lines that are parallel, are also in the same plane.

Three points given in space, and not in a straight, are necessary and sufficient for determining the position of a plane. Hence two planes which have three points common, coincide with each other.

The intersection of two planes is a straight line.

Plate III. When two planes ABCD, ABFE, *fig.* 1, intersect, they form between them a certain angle, which is called the inclination of the two planes, and which is measured by the angle contained by two lines; one drawn in each of the planes perpendicular to their line of common section.

Thus, if the line AF, in the plane ABEF, be perpendicular to AB, and the line AD, in the plane ABCD, be perpendicular also to AB, then the angle FAD is the measure of the inclination of the planes ABEF, ABCD. When the angle FAD is a right angle, the two planes are perpendicular.

Fig. 2. A line AB, is perpendicular to a plane PQ, when the line AB is perpendicular to any line BC in the plane PQ, which passes through the point B, where the line meets the plane. The point B is called the foot of the perpendicular.

A line AB, *fig.* 3, is parallel to a plane PQ, when the line AB is parallel to another straight line CD, in the plane PQ.

If a straight line have one of its intermediate points in common with a plane, the whole line will be in the plane.

Two planes are parallel to one another when they cannot intersect in any direction.

The intersections of two parallel planes with a third are parallel. Thus in *fig.* 4, the lines AB, CD, comprehended by the parallel plane PQ, RS, are parallel.

Any number of parallel lines comprised between two parallel planes, are all equal. Thus the parallel lines Aa, Bb, Cc, ... , comprised by the parallel planes PQ, RS, are all equal.

If two planes CDEF, GHIJ, *fig.* 6, are perpendicular to a third plane PQ, their intersection AB will be perpendicular to the third plane PQ.

If two straight lines be cut by several parallel planes, these straight lines will be divided in the same proportion.

SECTION IV.

OF THE RIGHT SECTIONS OF ARCHES OR VAULTS.

PROBLEM I.

To describe the arc of a circle which shall have a given tangent at a given point, and which shall touch another given arc.

Plate IV. Let B*k*, *fig.* 1, be one of the given arcs, and *lau* the other, and let it be required to describe the arc of a circle, which shall touch the arc B*k*, in the point *k*, and the arc *lau* in some point to be found; let *g* be the centre of the arc B*k*.

Draw *gk*, and make *kp* equal to the radius of the circle *lau*. Draw a straight line from *p* to *q*, the centre of the arc *lau*, and bisect *pq*, by a perpendicular, meeting *kg* in *m*. Join the points *m*, *q*, and prolong *mq* to *l*. It is manifest that *mk* and *ml* are equal; therefore, from *m* with the radius *mk* or *ml* describe an arc *kl*; and *kl* will be the arc required.

PROBLEM II.

To describe an oval, representing an ellipse, to any given dimensions of length and breadth, given in position.

Let A*a*, B*b*, *fig.* 2, be the two given lines bisecting each other in C; A*a* being equal to the length, and B*b* to the breadth.

Find a third proportional to this semi-axis C*a*, CB,* and make *ah* equal to the third proportional; also find a third proportional to CB, C*a*† and make B*g* equal to the third proportional.

Make the angle B*gk* equal to about 15°, and let *gk* meet A*a* in the point *i*. From *g* with the radius *g*B, describe an arc B*k*, and from *h* with the radius *ha*, describe an arc *la*. Describe the arc *kl* by the preceding problem to touch the arc B*k* in *k*, and to touch the arc *al* at *l*, and thus one quarter of the oval will be completed; the other three will be found by placing the centres in their proper positions.

Three or more points *a*, *b*, *c*, might easily have been found in the curve. Thus, draw A*d* parallel to B*b*, and B*d* parallel to CA. Divide A*d* into four equal parts, and divide AC also into four equal parts at 1, 2, 3. From *b* and through 1, 2, 3 in CA, draw *ba*, *bb*, *bc*, and from the points 1, 2, 3 in A*d*, draw towards B, to intersect the former in *a*, *b*, *c*, so that we may find the radius of curvature upon the sides, and at the two ends, by finding the centre of a circle passing through three points at each extremity, the extremity being the middle point.

---

* Thus in *fig.* 3, draw the two lines GA, AH making an angle with each other; make *ac* equal to *a*C, *fig.* 2, and A*d* equal to CB, *fig.* 2, and make A*e* equal to A*d*. Join *cd*, and draw *ef* parallel to *cd*; then *af* is the third perportional.

† That is, in *fig.* 3, make A*c* equal AG or *a*C, *fig.* 2, and A*d* equal to CB or C*b*, *fig.* 2, and make AG equal to A*c* and join *cd*. Draw GH parallel to *dc*; then AH is the third proportional.

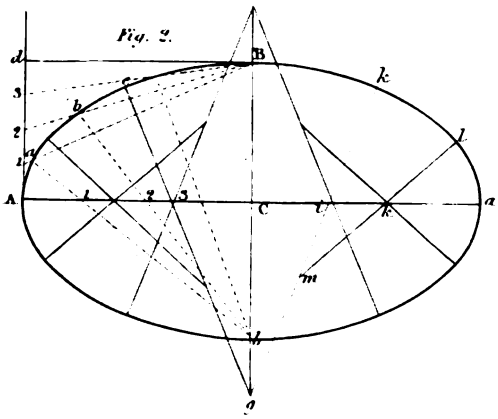
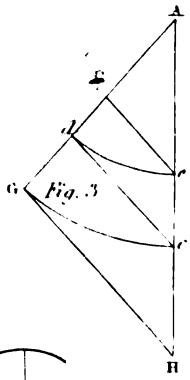


Fig. 2.
d
3
2
1
A
B
C
a
k
l
m
g


A
G
B
Fig. 3

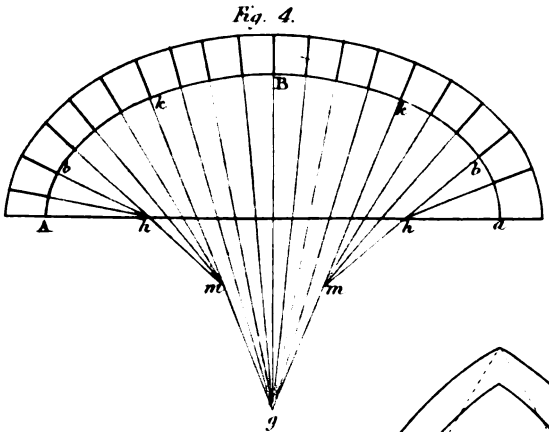


Fig. 4.
B
A
a
g

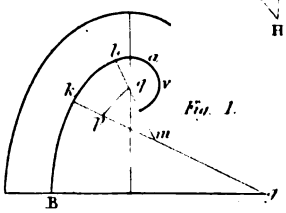


Fig. 1.
B

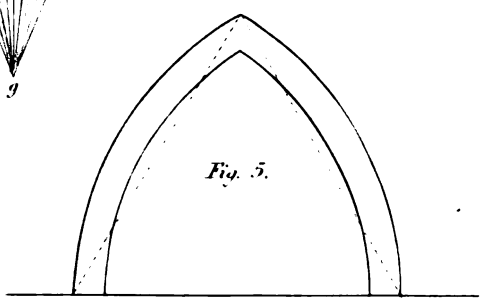


Fig. 5.

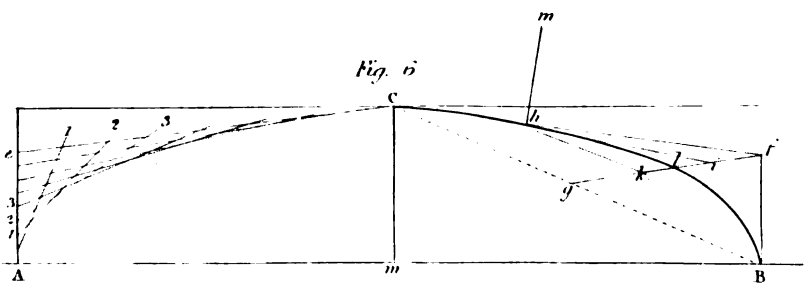


Fig. 6
m
C
A
B

Fig. 4 exhibits the use of this method of describing an oval, in finding the direction of the joints of arches so as to agree with the normals drawn from the several divisions of the inner arc. The arcs are marked the same as in figure 2.

REMARK.

When the height of the arch is equal to, or greater than half the span, and when it is not necessary that the vertical angle should be given, the curves of the intrados and extrados on the one side may be described from the same centre, as also those of the other side from another centre.

The most easy Gothic arch to describe, is that of which the height of the intrados is such as to be the perpendicular of an equilateral triangle, described upon the sparing line as a base, and these centres are the points to which the radiating joints must tend.

Gothic arches seldom exceed in height the perpendicular of the equilateral triangle inscribed in the intrados of the aperture; but when the arch is surmounted, and the height less than the perpendicular of the equilateral triangle made upon the base, draw a straight line from one extremity of the base to the vertex, and bisect this line by a perpendicular. From the point where the perpendicular meets the base of the arch, and with a radius equal to the distance between this point and the extremity of the base joined to the vertex, describe an arc between the two points, joined by the straight line, and the curve which forms one side of the intrados will be complete. In the same manner will be found the curve on the other side, see *fig.* 5, so that by only two centres the whole of the intrados will be formed.

The curves of all kinds of Gothic arches whatever, may be described by means of conic parabola, to a given vertical angle, and to any given dimensions. Thus in *fig.* 6, let C*e*, C*f*, be the two tangents, and A*e*, and B*f*, the heights of their extremities. Divide A*e* and *e*C each into the same number of equal parts by the points 1, 2, 3, in each of these lines. Draw lines from the corresponding points 1-1, 2-2, 3-3, &c.; and the intersections will form the curve of one side of the intrados, as we have already seen. The curve on the other side will be formed in the same manner.

Join BC, and bisect it in *g* and join *gt*, intersecting the curve in *l*. Draw *hk* parallel to CB, meeting *gf* in *k*. Make *li* equal to *lk*, and *ih* joined is a tangent at *h*. Hence, *hm* perpendicular to *hi*, is the joint.

CHAPTER IV.

SECTION I.

ON THE NATURE AND CONSTRUCTION OF TREHEDRALS.

DEFINITIONS.

Every stone bounded by six quadrilateral planes or faces forms a solid, of which the surfaces terminate on eight points, every three surfaces in one point. Every three planes thus terminating is termed a *solid angle* or *trehedral.*

The angles formed by the intersections of the faces with one another, or the three plain angles, are called sides of the trehedral, and the angles of inclination are called, by way of distinction from the other, simply *angles.*

The three sides, as well as the three angles, are each called a *part;* so that the whole trehedral consists of six parts; and if any three of these parts be given, the remaining three can be found.

Therefore, in bodies constructed of stone, which are intended to have their solid angles to consist of three plane angles, the construction of such bodies may be reduced to the consideration of the trehedral.

As to the remaining surface of the solid which incloses the solid, completely making a fourth side to the trehedral, it may be of any form whatever, regular or irregular, or consisting of many surfaces: it or they have nothing to do in the construction.

The parts of the trehedral, which may be obtained from three given parts, are the very same as three parts found in a spherical triangle from three given parts. This is, in fact, the same as spherical trigonometry.

We shall not, however, enter into any operose analytical investigations, but treat the subject in the most simple manner, according to the rules of solid geometry; and only those trehedrals, which have two of their planes at a right angle with each other, (though there are many cases in which the oblique trehedral would be necessary); as the bounds prescribed for this work will not admit of such an extension of the principles.

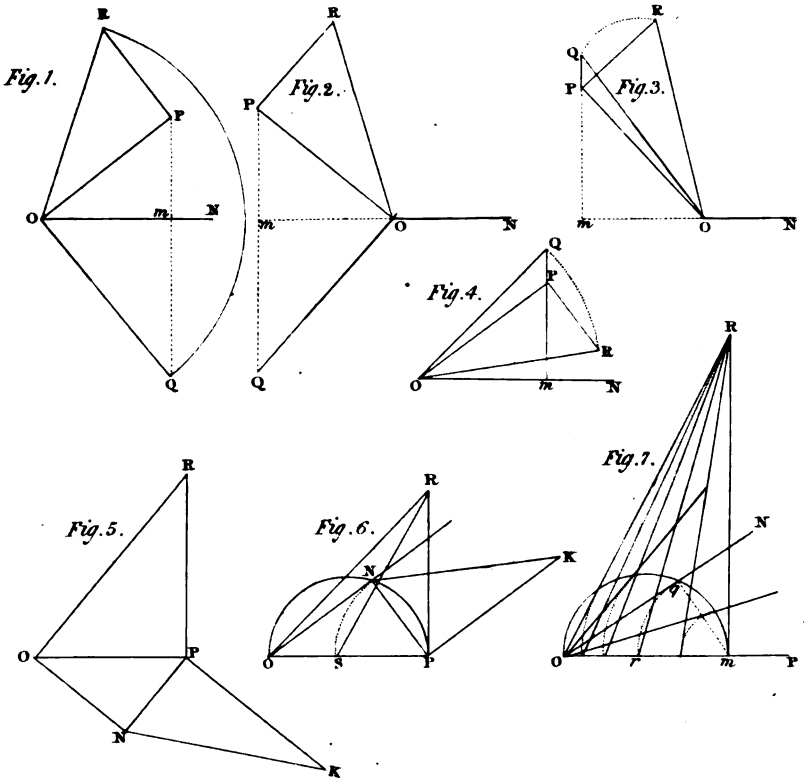


Fig. 1.
R
P
O
m
N
Q
Fig. 2.
R
P
m
O
N
Q
Fig. 3.
R
Q
P
m
O
N
Fig. 4.
Q
P
R
O
m
N
Fig. 5.
R
O
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Fig. 6.
R
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Fig. 7.
R
N
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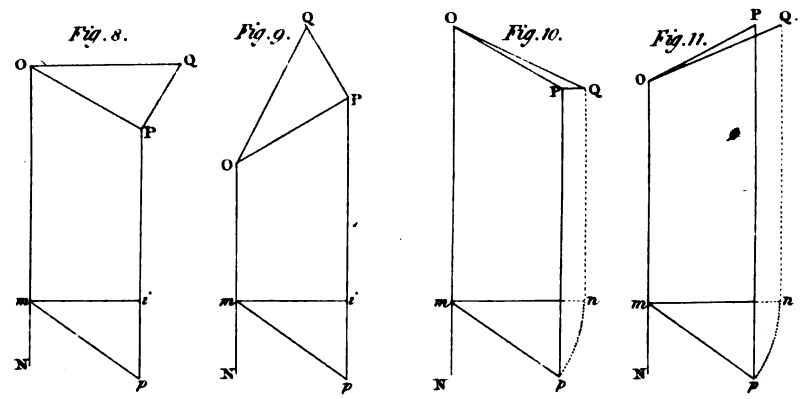


Fig. 8.
O
Q
P
m
i
N
p
Fig. 9.
Q
P
O
m
i
N
p
Fig. 10.
O
P
Q
m
n
N
p
Fig. 11.
P
Q
O
m
n
N
p

If the trehedral have two of its planes perpendicular to each other, it is called a *right angled trehedral*; each of the two faces thus forming a right angle, is called a *leg*, and the remaining side joining each leg, is called the hypothenuse.

PROBLEM I.

Given two legs of a right angled trehedral, to find the hypothenuse.

Plate V. *figs.* 1, 2, 3, 4. Let PON and POR be the given legs. Draw PR perpendicular to OP, and PQ perpendicular to ON. From O, as a centre with the radius OR, describe an arc intersecting PQ in Q, and join OQ, and QON is the hypothenuse required.

Demonstration.—Suppose the triangle POR revolved upon OP, until PR become perpendicular to the plane of the triangle OPN, then the plane of the triangle OPR will be perpendicular to the plane of the triangle OPN.

Again, suppose the triangle ONQ to revolve upon ON, and let PQ, or PQ produced intersect ON in *m*, then *m*Q will always be in a plane passing through P*m* and the plane described by *m*Q will be perpendicular to the plane *m*OP; and as PR is, by supposition, also perpendicular to the plane *m*OP, therefore PR and *m*Q being thus situated in the same plane will meet, except they are parallel.

Let *m*Q therefore be revolved until the straight line *m*Q fall upon the point R; let Q then be supposed to coincide with R; then because Q, by supposition, coincides with R, and the point O is common to the straight lines OQ and OR, therefore the straight lines OQ and OR having two common points will coincide, and therefore *m*OQ will be the hypothenuse required.

PROBLEM II.

Given the hypothenuse, and one of the legs, to find the other leg.

Figs. 1, 2, 3, 4. Let NOQ be the given hypothenuse and NOP the given leg, and let these two parts be attached to each other by the straight line ON.

In ON take any point *m*, and through *m* draw PQ perpendicular to ON. Draw PR perpendicular to OP. From the point O, with the radius OQ, describe an arc QR and join OR; then will POR be the other leg, as required.

These four diagrams show the various positions in which the data may be placed: every one will frequently occur in practice.

PROBLEM III.

Given the two legs of a right-angled trehedral, to find one of the angles at the hypothenuse.

Figs. 5, 6. Let the two given legs be PON and POR. In OP take any point P, and draw PN perpendicular to ON, and PR perpendicular to PO, and PK parallel to ON. Make PK equal to PR, and join NK; then PNK will be the angle at the hypothenuse.

In *fig.* 5, the two legs lie upon separate parts; and in *fig.* 6, one of the legs lies upon the other.

Fig. 7, exhibits the same principle applied in finding a series of bevels or angles made by the hypothenuse and a leg. Thus let the two legs be PON and POR. From any point *m* in OP draw *m*R perpendicular to OP. On O*m*, as a diameter, describe the semicircle O*qm*, intersecting ON in *q*, and join *qm*. Make *mr* equal to *mq*, and join *r*R; then P*r* R will be the angle required.

PROBLEM IV.

Given one of the legs and the inclination of the hypothenuse to that leg, to find the other leg.

Figs. 8, and 9. Let NOP be the given leg. In ON take any point *m*, and draw *mi* perpendicular to ON. Make *imp* equal to the angle which the leg NOP makes with the hypothenuse. Through any point *i*, in *mi*, draw P*p* parallel to ON, and PQ, perpendicular to OP. Make PQ equal to *ip*, and join OQ, and QOP will be the other leg.

PROBLEM V.

Given one of the legs and the angle which the hypothenuse forms with that leg to find the hypothenuse.

Figs. 10, and 11. In NO, take any point *m*, and draw *mn* perpendicular to ON. Make *nmp* equal to the angle which the hypothenuse makes with the leg NOP. From the point *m* as a centre with any radius, *mn* describe an arc *np*. Draw *p*P, *n*Q parallel to NO, and PQ perpendicular to NO, and join OQ; then NOQ is the hypothenuse required.

GENERAL APPLICATIONS OF THE TREHEDRAL TO TANGENT PLANES.

EXAMPLE I.

Given the inclination and seat of the axis of an oblique cylinder or cylindroid, to find the angle which a tangent makes at any point in the circumference of the base, with the plane of the base.

Figs. 1, 3, *Plate* VI. Let AEBO be the base of the cylinder or cylindroid, CB the seat of the axis, and let BCD be the angle of inclination, and let O be the point where the tangent plane touches the curved surface of the solid.

Draw ON a tangent line at the point O in the base, and draw OP parallel to CB. Make the angle POR equal to BCD, and draw PR perpendicular to PO.

Then, if the triangle POR be conceived to be revolved round the line PO as an axis, until its plane become perpendicular to the plane of the circle AEBC, the straight line OR will, in this position, coincide with the cylindrical surface, and a plane touching the cylinder or cylindroid at O, will pass through the lines ON and OR. Here will now be given the two legs POR and PON of a right angled trehedral to find the angle which the hypothenuse makes with the base. Draw PQ perpendicular to ON, intersecting it in *m*, and draw PS perpendicular to PQ. Make PS equal to PR, and join *m*S; then P*m*S is the angle required.

The hypothenuse will be easily constructed at the same time, thus—make *m*Q, equal to *m*S, and join OQ, then NOQ will be the hypothenuse required.

In *fig.* 1, the method of finding the angle which the tangent plane makes with the base and the hypothenuse is exhibited at four different points. In the two first points O from A in the first quadrant, the tangent planes make an acute angle at each point O; but in the second quadrant, they make an obtuse angle at each point O.

Fig. 2 is the second position of the construction from the point A, for finding the angle which the tangent plane makes with the base, and for finding the hypothenuse enlarged; in order to show a more convenient method by not only requiring less space, but less labor. It may be thus described, the two given legs being P′O′R′ and P′O′N′.

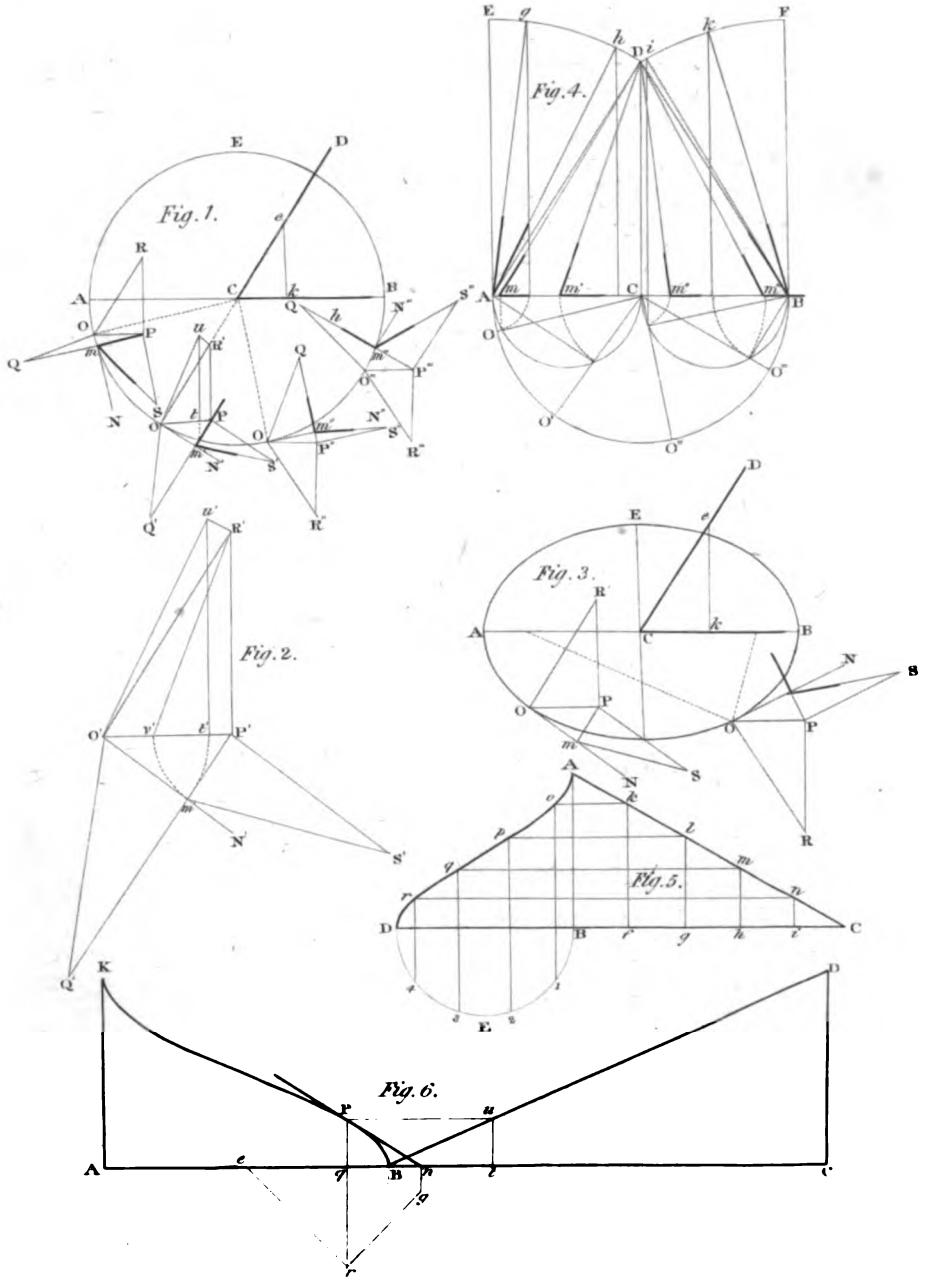


Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.

Draw P′*m*′ perpendicular to O′N′, meeting ON in *m*′. In P′O′, make P′*v*′ equal to P′*m*′, and draw the straight line *v*′R′, then P′*v*′R′ will be the inclination of the tangent plane at the point O.

Again in O′P′, make O′*t*′ equal to O′*m*′, and draw *t*′*u*′ parallel to P′R′. From O′, with the radius O′R′, describe an arc meeting *t*′*u*′ in *u*′, and draw the straight line O′*u*′; then *t*′O′*u*′ is the hypothenuse.

For since P′S′ is equal to P′R′, and P′*v*′ equal to P′*m*′, and the angles *m*′P′S′, and *v*′P′R′, are right angles; therefore the triangle *v*′P′R′ is equal to the triangle *m*′P′S′, and the remaining angles of the one, equal to the remaining angles of the other, each to each; hence the angle P′*v*′R′, is equal to the angle P′*m*′S′.

Again, because O′*t*′ is equal to O′*m*′, and O′Q′ is equal to O′R′, and O′*u*′ is also equal to O′R′; therefore O′*u*′ is equal to O′Q′, and since the angles O′*t*′*u*′ and O′*m*′Q′ are each a right angle, therefore the two right angled triangles have their hypothenuses equal to each other, and have also one leg in each, equal to each other; therefore the remaining side of the one triangle is equal to the remaining side of the other, and therefore also the angles which are opposite to the equal sides are equal; hence the angle P′O′*u*′ is equal to N′O′Q′.

By considering this construction by the transposition of the triangles, the whole of the angles which the tangent planes make at a series of points O in figures 1 and 3, and their hypothenuses may be all found in one diagram, as in figure 4.

Thus, in *fig.* 4, if the angles ACO, ACO′, ACO″, ACO‴ be respectively equal to ACO, ACO′, ACO″, ACO‴, *fig.* 1, and in *fig.* 4, the semicircle AO′B be described and if CD be drawn perpendicular to AB, and the angles CAD, CBD, be made equal to BCD, *fig.* 1; then each half of *fig.* 4, being constructed as in *fig.* 2; the angles at *m*, *m*′, *m*″, *m*‴, will be respectively equal to the angle P*m*S, P′*m*′S′, Q″*m*″S″, Q‴*m*‴S‴, in *fig.* 1.

Also, in *fig.* 4, the angles CAE, CA*g*, CA*h*, CB*i*, CB*k*, CBF will be the hypothenuses at the point A, O, O′ O″, O‴, B in *fig.* 1.

We may here observe, *fig.* 1, that the angles which the tangent planes make with the plane of the base in the first quadrant are acute; and those in the second quadrant are obtuse; and those in the second quadrant are the supplements of the angles P*m*S; and, moreover, that all the angles which constitute the hypothenuses of the trehedral, are all acute, whether in the first quadrant or second quadrant of the semicircle AOB.

SECTION II.

ON THE PROJECTION OF A STRAIGHT LINE BENT UPON A CYLINDRIC SURFACE, AND THE METHOD OF DRAWING A TANGENT TO SUCH A PROJECTION.

PROBLEM I.

Given the developement of the surface of the semi-cylinder, and a straight line in that developement, to find the projection of the straight line on a plane passing through the axis of the cylinder, supposing the developement to encase the semi-cylindric surface.

Fig. 5. Let ABC be the developement of the cylindric surface, BC being the developement of the semi-circumference, and let AC be the straight line given.

Produce CB to D, making BD equal to the diameter of the cylinder. On BD, as a diameter, describe the semi-circle BED, and divide the semi-circular arc BED, into any number of equal parts, at 1, 2, 3, &c.; and its developement BC into the same number of equal parts, at the points *f*, *g*, *h*, &c. Draw the straight lines *fk*, *gl*, *hm*, &c. parallel to BA, meeting AC at the points *k*, *l*, *m*, &c.; also parallel to BA, draw the straight lines 1*o*, 2*p*, 3*q*, &c. and draw *ko*, *lp*, *mq*, &c. parallel to CD; and the points *o*, *p*, *q*, &c. are the projections or seats of the points *k*, *l*, *m*, &c. in the developement of the straight line AC.

The projection of a screw is found by this method: BD may be considered as the diameter of the cylinder from which the screw is formed; and the angle BAC, the inclination of the thread with a straight line on the surface; or BCA the inclination of the thread with the end of the cylinder. The same principle also applies to the delineations of the hand-rails of stairs, and in the construction of bevel bridges.

PROBLEM II.

Given the entire projection of a helix or screw, in the surface of a semi-cylinder, and the projection of a circle in that surface perpendicular to the axis, upon the plane passing through the axis, to draw a tangent to the curve at a given point.

Fig. 6. Let BPK be the projection of the helix or screw, and BA the projection of the circumference of a circle, and since this circle is in a plane perpendicular to the plane of projection, it will be projected into a straight line AB, equal to the diameter of the cylinder.

On AB as a diameter, describe the semicircle A*r*B, and draw P*r* perpendicular to, and intersecting AB in *q*, join the points *e*, *r*, and produce *er* to *f*.

Produce AB to C, so that BC may be equal to the semicircular arc B*r*A. Draw CD perpendicular to BC, and make CD equal to AK, and draw the straight line BD; then BD will be the developement of the curve line BPK.

Draw P*u* parallel to AC, meeting BD in *u*, and draw *ut* perpendicular to BC. Draw *rg* perpendicular to *er*, and make *rg* equal to B*t*. Draw *gn* perpendicular to AC, meeting BC in *n*, and draw the straight line *n*P; then *n*P will touch the curve at the point P.

Or the tangent may be drawn independent of BCD thus: Draw P*r* perpendicular to AB, and *rg* a tangent at *r*. Make *rg* equal to the developement of *r*B, and draw *gn* perpendicular to BC, meeting BC in *n*, and join *n*P, which is the tangent required.

Fig. 1.

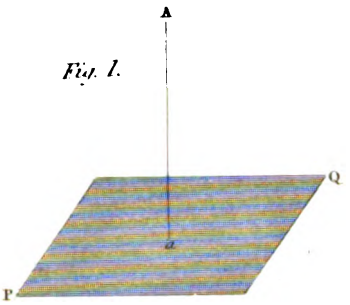


Fig. 2.

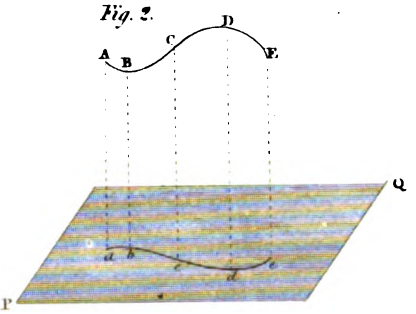


Fig. 3.

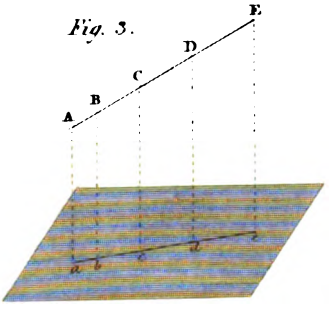


Fig. 4.

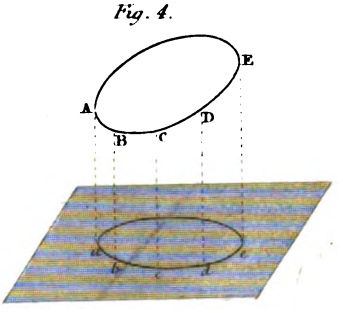


Fig. 5.

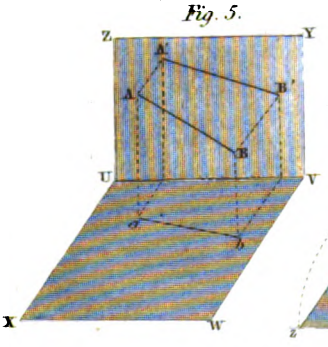
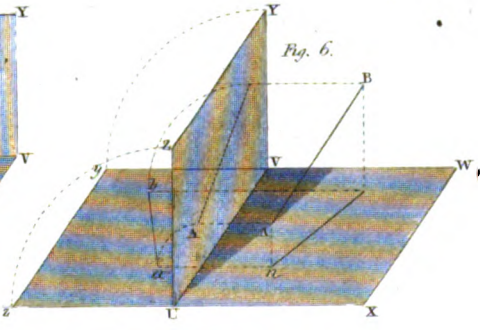


Fig. 6.



SECTION III.

APPLICATION OF GEOMETRY TO PLANES AND ELEVATIONS, AND ALSO TO THE CONSTRUCTION OF ARCHES AND VAULTS.

PRELIMINARY PRINCIPLES OF PROJECTION.

If from a point A′, *Plate VII. fig.* 1 in space, a perpendicular A′*a* be let fall to any plane PQ whatever, the foot *a* of this perpendicular is called the *projection* of the point A′ upon the plane PQ.

If through different points A′, B′, C′, D′ . . . . *figs.* 2, 3, 4, of any line A′B′C′D′ . . . . . whatever in space, perpendiculars A′*a*, B′*b*, C′*c*, D′*d*, ... be let fall upon any plane PQ whatever, and if through *a*, *b*, *c*, *d*, ... the projection of the points A′, B′, C′, D′, ... in the plane PQ a line be drawn, the line thus drawn will be the projection of the line A′B′C′D′ . . . . given in space.

If the line A′B′C′D′ . . . . . *fig.* 3, be straight, the projection *abcd* . . . . will also be a straight line; and if the line A′B′C′D . . . . *fig.* 2, be a curve not in a plane perpendicular to the plane PQ, the curve *abcd* . . . . which is the projection of the curve A′B′C′D′ . . . . in space, will be of the same species with the original curve, of which it is the projection. Hence, in this case, if the original curve A′B′C′D . . . . be an ellipse, a parabola, hyperbola, &c., the projection *abcd* . . . . will be an ellipse, a parabola, an hyperbola, &c. The circle and the ellipse being of the same species, the projected curve may be a circle or ellipse, whether the original be a circle or ellipse, as in *fig.* 4.

The plane in which the projection of any point, line, or plane figure is situated, is called the plane of projection, and the point or line to be projected is called the primitive.

The projection of a curve will be a straight line when the curve to be projected is in a plane perpendicular to the plane of projection. Hence the projection of a plane curve is a straight line.

If a curve be situated in a plane which is parallel to the plane of projection, the projection of the curve will be another curve equal and similar to the curve of which it is the projection.

The projection upon a plane of any curve of double curvature whatever is always a curve line.

In order to fix the position and form of any line whatever in space, the position of the line is given to each of two planes which are perpendicular to each other; the one is called the horizontal plane and the other the vertical plane; the projection of the line in question is made on each of these two planes, and the two projections are called the two projections of the line to be projected.

Thus we see in *fig.* 5, where the parallelogram UVWX represents the horizontal plane, and the parallelogram UVYZ represents the vertical plane, the projection *ab* of the line A′B′ in space upon the horizontal plane UVWX, is called the horizontal projection, and the

projection AB of the same line upon the vertical plane UVYZ, is called the *vertical projection*.

The two planes, upon which we project any line whatever, are called the planes of projection.

The intersection UV of the two planes of projection, is called the ground line.

When we have two projections *ab*, AB of any line A'B' in space, the line A'B' will be determined by erecting to the planes of projection the perpendiculars *a*A', B*b*' . . . ., A A', B B'. . . . . through the projections *a*, *b*, ... ; A, B, ... of the original points A' B', ... of the line in question. For the perpendiculars *a*A', AA erected from the projections *a*, A of the same point A' will intersect each other in space in a point A', which will be one of these in the line in question. It is clear that the other points must be found in the same manner as this which has now been done.

When we have obtained the two projections of a line in space, whether immediately from the line itself, or by any other means whatever, we must abandon this line in order to consider its two projections only. Since, when we design a working drawing, we operate only upon the two projections of this line that we have brought together upon one plane, and we no longer see any thing in space.

However, to conceive that which we design, it is absolutely necessary to carry by thought the operations into space from their projections. This is the most difficult part that a beginner has to surmount, particularly when he has to consider at the same time a great number of lines in various positions in space.

The perpendicular A'*a*, *fig.* 5, let fall from any point A whatever in space upon the plane XV of projection, is called the projectant of the point A' upon this plane. Moreover, the perpendicular distance between the point A' and the horizontal plane XV, is called the projectant upon the horizontal plane, or simply the horizontal projectant; and the perpendicular distance A'A between the original point A' and the vertical plane UY, is called the projectant upon the vertical plane, or simply the vertical projection.

We shall remark, so as to prevent any mistake, that the horizontal projectant A'*a*, is the perpendicular let fall from the original point upon the horizontal plane, and that the vertical projectant is the perpendicular let fall from that point upon the vertical plane. Hence the horizontal projectant is parallel to the vertical plane, and is equal to the distance between the original point and the horizontal plane; and the vertical projectant is parallel to the horizontal plane, and is equal to the distance between the original point and the vertical plane.

We may remark, that if through *a*, *fig.* 6, the horizontal projection of the point A' we draw a perpendicular *a*a to UV the ground line, this perpendicular *a*a will be equal to the measure of the vertical projectant A'A; consequently the distance of the point A' to the vertical plane is equal to the distance between *a*, its horizontal projection, and UV the ground line measured in a perpendicular to UV. In like manner, if through A, the vertical projection of the point A',

we draw a perpendicular A*a* to UV the ground line, this perpendicular A*a* will be equal to the measure of the horizontal projectant A*a*; consequently, the distance of this point A′ to the horizontal plane, is equal to the distance between A its vertical projection, and UV the ground line measured in a perpendicular to UV.

To these very important remarks we shall add one which is not less so. Two perpendiculars, *a*a, *fig.* 6, Aa, being let fall from the projections *a*, A to the same point A′, upon the ground line UV, will meet each other in the same point a, of the said ground line UV.

If we now wished the two projections of a point A′, *fig.* 6, or of any line A′B′ whatever, to be upon one or the same plane, it is sufficient to imagine the vertical plane UVYZ to turn round the ground-line UV, in such a manner as to be the prolongation of the horizontal plane UVWX; for it is clear that this plane will carry with it the vertical projection A or AB of the point, or of the line in question. Moreover we see, and it is very important that the lines Aa, Bb, perpendicular to the ground-line UV will not cease to be so in the motion of the plane UVYZ; and as the corresponding lines *a*a, *b*b, are also perpendiculars to the ground line UV, it follows that the lines a*a*′, *b*b′, will be the respective prolongation of the lines *a*a, *b*b.

Hence it results, when we consider objects upon a single plane, the projections *a*, A of the point A′ in space are necessarily upon the same perpendicular A*a* to the ground-line UV.

It is necessary to call to mind that the distance Aa measures the distance from the point in space to the horizontal plane, (the point A being the vertical projection of this point,) and that the line *a*a measures the distance from the same point in space to the vertical plane.

It follows, that if the point in space be upon the horizontal plane, its distance with regard to this last-named plane will be zero or nothing, and the vertical Aa will be zero also. Moreover, the vertical projection of this point will be upon the ground-line at the foot a, of the perpendicular *a*a let fall upon the ground-line, from the horizontal projection *a* of this point.

Again, if the point in space be upon the vertical plane, its distance, in respect of this plane, will be zero, the horizontal *a*a will be zero, and the horizontal projection of the point in question will be the foot a of the perpendicular Aa let fall upon the ground-line from the vertical projection A of this point.

In general, we suppose that the vertical projection of a point is above the ground-line, and that the horizontal projection is below; but from what has been said, it is evident that if the point in space be situated below the horizontal line, its vertical projection will be below the ground-line; for the distance from this point to the horizontal plane, cannot be taken from the base-line to the top, but from the top to the base with respect to its plane.

So if the point in space be situated behind the vertical plane, its horizontal projection will be above the ground-line, from which we conclude—

1st. If the point in question be situated above the horizontal plane,

and before the vertical plane, its vertical projection will be above, and its horizontal projection below the ground-line.

2d. If the point be situated before the vertical plane, and below the horizontal plane, the two projections will be below the ground-line.

3d. If the point be situated above the horizontal plane, but behind the vertical plane, the two projections will be above the ground-line.

4th. Lastly. If the point be situated above the horizontal plane, and behind the vertical plane, the vertical projection will be below, and the horizontal projection above, the ground-line.

The reciprocals of these propositions are also true.

If a line be parallel to one of the planes of projection, its projection upon the other plane will be parallel to the ground-line. Thus, for example, if a line be parallel to a horizontal plane, its vertical projection will be parallel to the ground line; and if it is parallel to the vertical plane, its horizontal projection will be parallel to the ground-line.

Reciprocally, if one of the projections of a line be parallel to the ground line, this line will be parallel to the plane of the other projection. Thus, for example, if the vertical projection of a line be parallel to the ground-line, this line will be parallel to the horizontal plane, and *vice versa*.

If a line be at any time parallel to the two planes of projection, the two projections of this line will be parallel to the ground-line; and reciprocally, if the two projections of a line be parallel to the ground-line, the line itself will be at the same time parallel to the two planes of projection.

If a line be perpendicular to one of the planes of projection, its projection upon this plane will only be a point, and its projection upon the other plane will be perpendicular to the ground-line. Thus, for example, if the line in question be perpendicular to the horizontal plane, its horizontal projection will be only a point, and its vertical projection will be perpendicular to the ground-line.

Reciprocally, if one of the projections of a straight line be a point, and the projection of the other perpendicular to the ground-line, this line will be perpendicular to the plane of projection upon which its projection is a point. Thus the line will be perpendicular to the horizontal plane, if its projection be the given point in the horizontal plane.

If a line be perpendicular to the ground-line, the two projections will also be perpendicular to this line. The reciprocal is not true; that is to say, that the two projections of a line may be perpendicular to the ground-line, without having the same line perpendicular to the ground-line.

If a line be situated in one of the planes of projection, its projection upon the other will be upon the ground-line. Thus, if a line be situated upon a horizontal plane, its vertical projection will be upon the ground-line; and if this line were given upon the vertical plane, its horizontal projection would be upon the ground-line.

Reciprocally, if one of the projections of a line be upon the ground-line, this line will be upon the plane of the other projection. Thus,

for example, if it be the vertical projection of the line in question which is upon the ground, this line will be upon the horizontal plane; if, on the contrary, it were upon the horizontal projection of this line which was upon the ground-line, this line would be upon the vertical plane.

If a line be at any time upon the two planes of projection, the two projections of this line would be upon the ground-line, and the line in question would coincide with this ground-line. Reciprocally, if the two projections of a line were upon the ground-line, the line itself would be upon the ground-line.

If two lines in space are parallel, their projections upon each plane of projection are also parallel. Reciprocally, if the projections of two lines are parallel on each plane of projection, the two lines will be parallel to one another in space.

If any two lines whatever in space cut each other, the projections of their point of intersection will be upon the same perpendicular line to the ground-line, and upon the points of intersection of the projections of these lines. Reciprocally, if the projections of any two lines whatever cut each other in the two planes of projection, in such a manner that their points of intersection are upon the same perpendicular to the ground-line, these two lines in question will cut each other in space.

The position of a plane is determined in space, when we know the intersections of this plane with the planes of projection.

The intersections AB, AC, of the plane in question, with the planes of projection, are called the *traces* of this plane.

The trace situated in the horizontal plane is called the *horizontal trace*, and the trace situated in the vertical plane is called the *vertical trace*.

A very important remark is, that the two traces of a plane intersect each other upon the ground-line.

If a plane be parallel to one of the planes of projection, this plane will have only one trace, which will be parallel to the ground-line, and situated in the other plane of projection. Reciprocally, if a plane has a trace parallel to the ground-line, this plane will be parallel to the plane of projection which does not contain this trace. Thus:—

1st. If a plane be parallel to the horizontal plane, this plane will not have a horizontal trace, and its vertical trace will be parallel to the ground-line. Likewise, if a plane be parallel to the vertical plane, this plane will not have a vertical trace, and its horizontal trace will be parallel to the ground-line.

2d. If a plane has only one trace, and this trace parallel to the ground-line, let it be in the vertical plane; then the plane will be parallel to the horizontal plane. So if the trace of the plane be in the horizontal plane, and parallel to the ground-line, the plane will be parallel to the vertical plane.

If one of the traces of a plane be perpendicular to the ground-line, and the other trace in any position whatever, this plane will be perpendicular to the plane of projection in which the second trace is. Thus, if it be a horizontal trace which is perpendicular to the ground-line, the plane will be perpendicular to the vertical plane of

projection ; and if, on the contrary, the vertical trace be that which is perpendicular to the ground-line, then the plane will be perpendicular to the horizontal plane.

Reciprocally, if a plane be perpendicular to one of the planes of projection without being parallel to the other, its trace upon the plane of projection to which it is perpendicular will be to any position whatever, and the other trace will be perpendicular to the ground-line. Thus, for example, if the plane be perpendicular to the vertical plane, the vertical trace will be in any position whatever, and its horizontal trace will be perpendicular to the ground-line. The reverse will also be true, if the plane be perpendicular to the horizontal plane.

If a plane be perpendicular to the two planes of projection, its two traces will be perpendicular to the ground-line. Reciprocally, if the two traces of a plane are in the same straight line perpendicular to the ground-line, this plane will be perpendicular to both the planes of projection.

If the two traces of a plane are parallel to the ground-line, this plane will be also parallel to the ground-line. Reciprocally, if a plane be parallel to the ground-line, its two traces will be parallel to the ground-line.

When a plane is not parallel to either of the planes of projection, and one of its traces is parallel to the ground-line, the other trace is also necessarily parallel to the ground-line.

If two planes are parallel, their traces in each of the planes of projection will also be parallel. Reciprocally, if on each plane of projection the traces of the two planes are parallel, the planes will also be parallel.

If a line be perpendicular to a plane, the projections of this line will be in each plane of projection, perpendicular to the respective traces in this plane. Reciprocally, if the projections of a line are respectively perpendicular to the traces of a plane, the line will be perpendicular to the plane.

If a line be situated in a given plane by its traces, this line can only intersect the planes of projection upon the traces of the plane which contains it. Moreover, the line in question can only meet the plane of projection in its own projection. Whence it follows, that the points of meeting of the right line, and the planes of projection are respectively upon the intersections of this right line, and the traces of the plane which contains it.

If a right line, situated in a given plane by its traces, is parallel to the horizontal plane, its horizontal projection will be parallel to the horizontal trace of the given plane, and its vertical projection will be parallel to the ground-line. Likewise, if the right line situated in a given plane by its traces is parallel to the vertical plane, its vertical projection will be parallel to the vertical line of the plane which contains it, and its horizontal projection will be parallel to the ground-line.

Reciprocally, if a line be situated in a given plane by its traces, and that, for example, let its horizontal projection be parallel to the horizontal trace of the given plane, this line will be parallel to the horizontal plane, and its vertical projection will be parallel to the

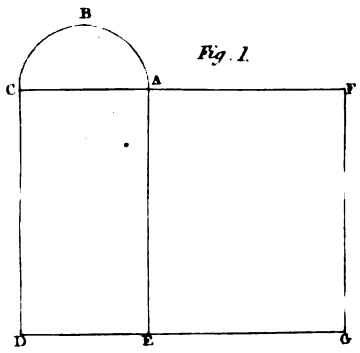


Fig. 1.

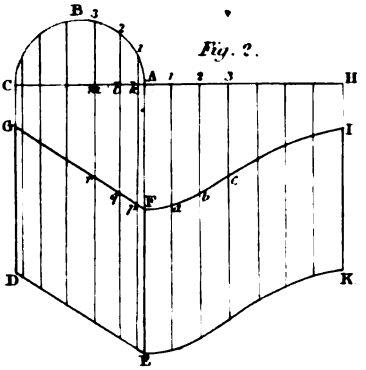


Fig. 2.

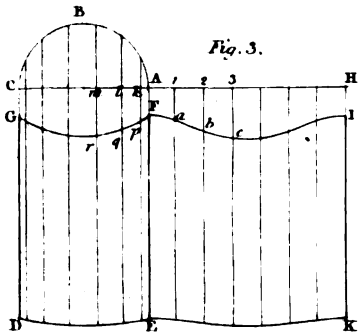


Fig. 3.

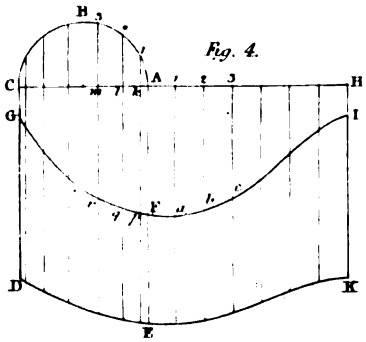


Fig. 4.

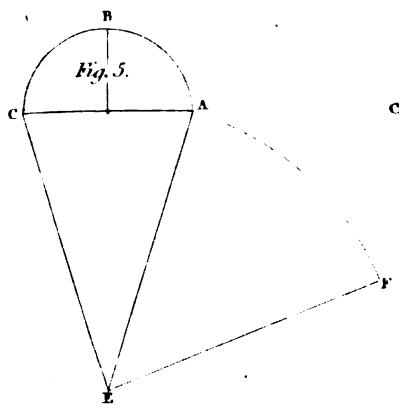


Fig. 5.

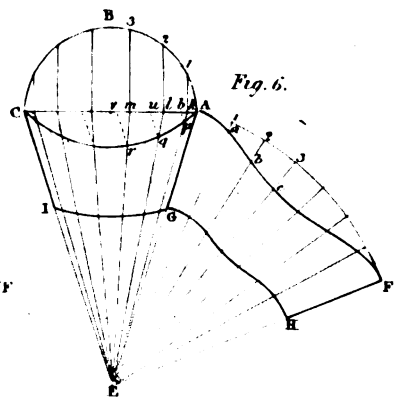


Fig. 6.

ground-line. Likewise, if the vertical projection of the line in question be parallel to the vertical trace of the given plane, this line will be parallel to the vertical plane, and its horizontal projection will be parallel to the ground-line.

SECTION IV.

ON THE DEVELOPEMENTS OF THE SURFACES OF SOLIDS.

PROBLEM I.

To find the developement of the surface of a right semi-cylinder.

Plate 8, *fig.* 1. Let ACDE be the plane passing through the axis. On AC, as a diameter, describe the semicircular arc ABC. Produce CA to F, and make AF equal to the developement of the arc ABC. Draw FG parallel to AE, and EG parallel to AF; then AFGE is the developement required.

PROBLEM II.

To find the developement of that part of a semi-cylinder contained between two perpendicular surfaces.

Figs. 2, 3, 4. Let ACDE be a portion of a plane passing through the axis of the cylinder, CD and AE, being sections of the surface, and let DE and GF be be the insisting lines of the perpendicular surface; also let AC be perpendicular to AE and CD. On AC, as a diameter, describe the semi-circular arc ABC. Produce CA to H, and make AH equal to the developement of the arc ABC. Divide the arc ABC, and its developement, each into the same number of equal parts at the points 1, 2, 3.

Through the points 1, 2, 3, &c. in the semi-circular arc and in its developement, draw straight lines parallel to AE, and let the parallel lines through 1, 2, 3, in the arc A, B, C, meet FG in *p*, *q*, *r*, &c. and AC in *k*, *l*, *m*, &c. Transfer the distances *kp*, *lq*, *mr*, &c. to the developement upon the lines 1*a*, 2*b*, 3*c*, &c. Through the points F, *a*, *b*, *c*, &c. draw the curve line F*c*I. In the same manner draw the curve line EK; then FEKI will be the developement required.

PROBLEM III.

To find the developement of the half surface of a right cone, terminated by a plane passing through the axis.

Fig. 5. Let ACE be the section of the cone passing along the axes AE; and CE the straight lines which terminate the conic surface, or the two lines which are common to the section CAE and the conic surface; and let AC be the line of common section of the axal plane, and the base of the cone.

On AC as a diameter describe a semi-circle ABC. From E, with the radius EA, describe the arc AF and make the arc AF equal to the semi-circular arc ABC, and join EF; then the sector AEF, is the developement of the portion of the conic surface required.

PROBLEM IV.

To find the developement of that portion of a conic surface contained by a plane passing along the axis, and two surfaces perpendicular to that plane.

Fig. 6. Let ACE be the section of the cone along the axis, and let AC and GI be the insisting lines of the perpendicular surfaces. Find the developement AEF as in the preceding problem. Divide the semi-circular arc ABC, and the sectorial arc AF, each into the same number of equal parts at the points 1, 2, 3, &c. From the points 1, 2, 3, &c. in the semi-circular arc draw straight lines 1*k*, 2*l*, 3*m*, &c. perpendicular to AC. From the points *k*, *l*, *m*, &c. draw straight lines *k*E, *l*E, *m*E, &c. intersecting the curve AC in *p*, *q*, *r*, &c. Draw the straight lines *pt*, *qu*, *rv*, &c. parallel to one side, EC meeting AC in the points *t*, *u*, *v*, &c. Also from the points 1, 2, 3, in the sectorial arc AF, draw the straight lines 1E, 2E, 3E, &c. Transfer the distances *pt*, *qu*, *rv*, &c. to 1*a*, 2*b*, 3*c*, &c.; then through the points A, *a*, *b*, *c*, &c. draw the curve AcF, and AcF is one of the edges of the developement, and by drawing the other edge, the entire developement, AGHF, will be found.

SECTION V.

CONSTRUCTION OF THE MOULDS FOR HORIZONTAL CYLINDRETIC VAULTS, EITHER TERMINATING RIGHTLY OR OBLIQUELY, UPON PLANE OR CYLINDRICAL WALLS, WITH THE JOINTS OF THE COURSES EITHER IN THE DIRECTION OF THE VAULT, PERPENDICULAR TO THE FACES, OR IN SPIRAL COURSES.

DEFINITIONS OF MASONRY, WALLS, VAULTS, &c.

Stone-cutting is the art of reducing stones to such forms that when united together they shall form a determinate whole.

In preparing stones for walls, of which their surfaces are intended to be perpendicular to the horizon, nothing more is necessary than to reduce the stone to its dimensions, so that each of its eight solid angles may be contained by three plane right angles.

Moreover, in working the stones of common straight right cylindretic vaults, where the planes of the sides of the joints terminate upon the intrados or extrados of the arch or vault, in straight lines parallel ruled lines of the cylindretic surface, there can be no difficulty ; for if one of the beds of the stone be formed to a plane surface, and if this side be figured to the mould, and the opposite ends squared, and, lastly, the face or vertical moulds applied upon the ends thus squared, and their figures drawn, these figures will be the two ends of a prism, consisting of equal and similar figures, and will be similarly situated ; and therefore we have only to form this prism, in order to form the arch-stone required.

But the formation of the stones in the angles of vaults, and in the courses of spheretical niches and domes, are much more difficult, and require more consideration. In such constructions various methods may be employed, and some of these, in particular instances, with great advantage, both in the saving of workmanship and material, as we shall have occasion to show. In general, however, previous to the reducing of a stone to its ultimate form for such a situation, it will be found convenient to reduce the stone to such a figure as will include the more complex figure of the stone required, so that any surface of the preparatory figure may either include a surface or arris of the stone required to be formed, or be a tangent to their surface.

Surfaces are brought to form by means of straight and curved edges, always applied in a plane perpendicular to the arris-lines, so that, when a surface is thoroughly formed, the edge of application may have all its points in contact with the surface in its whole intended breadth.

A wall, in masonry, is a mass of stones or other material, either joined together with or without cement, so as to have its surfaces such that a plumb-line, descending from any point in either face, will not fall without the solid.

One of the faces of a wall is generally regulated by the other, and the regulating surface is called the principal face.

The line of intersection of the principal face of a wall, and a horizontal plane on a level with the ground, or as nearly so as circumstances will permit, is called *the base-line*.

A horizontal section of a wall, through the base-line, is called *the seat of the wall*.

The other side of the seat of a wall, opposite to the base-line, is called *the rear-line*.

In exterior walls the outer surface is always the principal face, and the base and rear-lines are generally so situated, that normals drawn to the base-line, between the base and rear-lines, are all equal to one another. This uniformity most frequently takes place also in partition or division walls; but, in some instances, on account of a room being circular or elliptical, while the other faces are plane or curved surfaces, this equality of the normals cannot subsist.

If a wall be cut by a plane perpendicular to the base-line, or if the base-line be a curve perpendicular to a tangent through the point of contact, such a section is called *a right section*.

Hence, according to this definition, since the base-line is always in a horizontal plane, every straight line and every tangent to a base-line, when it is a curve, will be a horizontal line, therefore the right section must be in a vertical plane.

Walls are denominated according to the figure of their base-line. When the base-line is straight, the wall is said to be straight. Hence, if the figure of the base be an arc or the whole circumference of a circle, or a portion or the entire curve of an ellipse, the wall is said to be circular or elliptical. Other forms seldom occur in building.

Walls are more strictly defined by the joint consideration of the figures of their bases and right section.

When the base and the right section of a wall are each a straight line, and all the horizontal sections straight lines, the face of the wall is called a ruler surface, and if all the right sections have the same inclination, the wall is called a straight inclined wall; if they are all vertical, the wall is called an erect straight wall, or a vertical straight wall. If the right sections vary their inclination, the wall is called *a winding wall.*

When the base line is the circumference or any arc of a circle, and the right section a straight line perpendicular to the horizon, the wall is said to be cylindric. If the right sections of a wall be all equally inclined to the horizon, the wall is said to be conic; and thus a wall takes also the name by which its surface is called; hence a straight wall, which has its right sections either vertical or at the same inclination, is called *a plane wall.*

A wall in tallus, or *a battering wall*, is that of which the vertical section of the principal face is a straight line not perpendicular to the horizon. This vertical section is called the *tallus-line.*

The horizontal distance between the foot of the tallus-line and the plumb-line, passing through its upper extremity, is called the *quantity of batter;* and the plumb-line, from the top of the tallus-line to the level of its foot, is called *the vertical of the batter.*

The interstices between the stones, for the insertion of cement or mortar, in order to connect the stones into one solid mass, are called *joints*, and the surfaces of the stones between which the mortar is inserted, are called *the sides of the joints.*

When the sides of the joints are everywhere perpendicular to the face of a wall, and terminate in horizontal planes upon that face, such joints are called *coursing joints;* and the row of stones between every two coursing joints, is called *a course of stones.*

An *arch* or *vault*, in masonry, is a mass of stones suspended over a hollow, and supported by one or more walls at its extremities, the surface opposed to the hollow being concave, and such that a vertical line, descending from any point in the curved surface, may not meet the curved surface in another point.

The concave surface under the arch or vault, is called *the intrados* of that arch or vault; and if the upper surface be convex, this convex surface is called *the extrados.*

Those joints which terminate upon the intrados in horizontal lines, are called *coursing joints*, and the coursing joints will either be straight, circular, or elliptic, accordingly as the horizontal sections of the intrados are straight, circular, or elliptic.

Whether in walling or in vaulting, the joints of the stones should always be perpendicular to the face of the wall, or to the intrados of the arch, and the joints between the stones should either be in planes perpendicular to the horizon, or in surfaces which terminate upon the face of the wall or intrados of a vault in horizontal planes; these positions being necessary to the strength, solidity, and durability of the work.

Walls and vaults being of various forms; viz. straight, circular, and elliptic, depending on the plan of the work; hence the construction will depend upon the simple figure or upon the complex figure when combined in two.

Fig. 1.

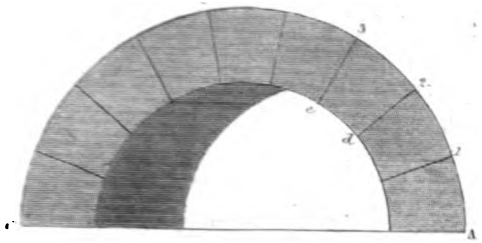


Fig. 5.

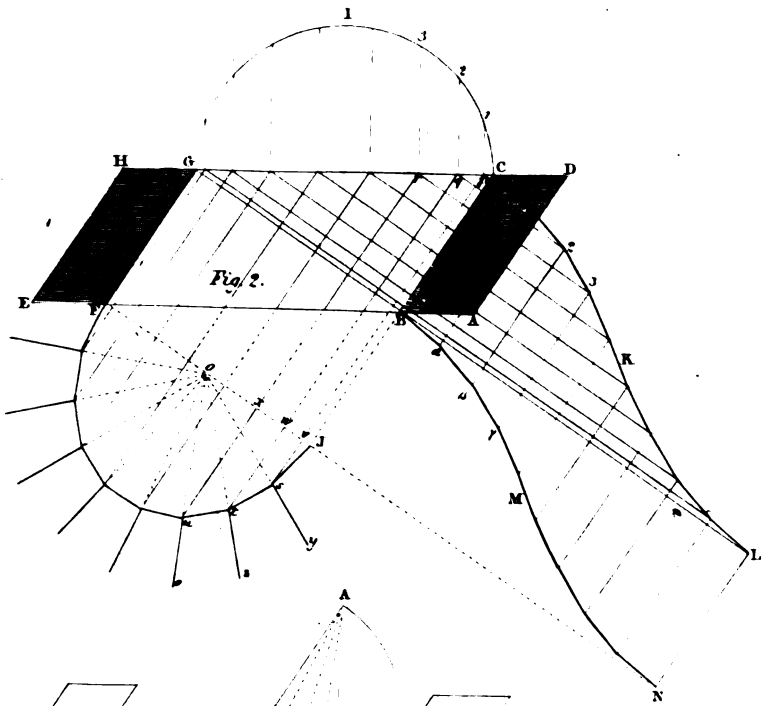


Fig. 2.

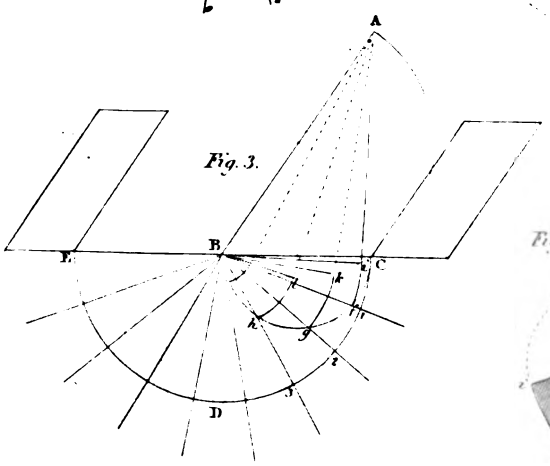
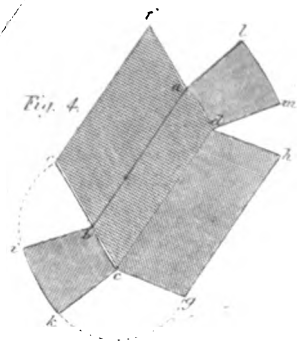
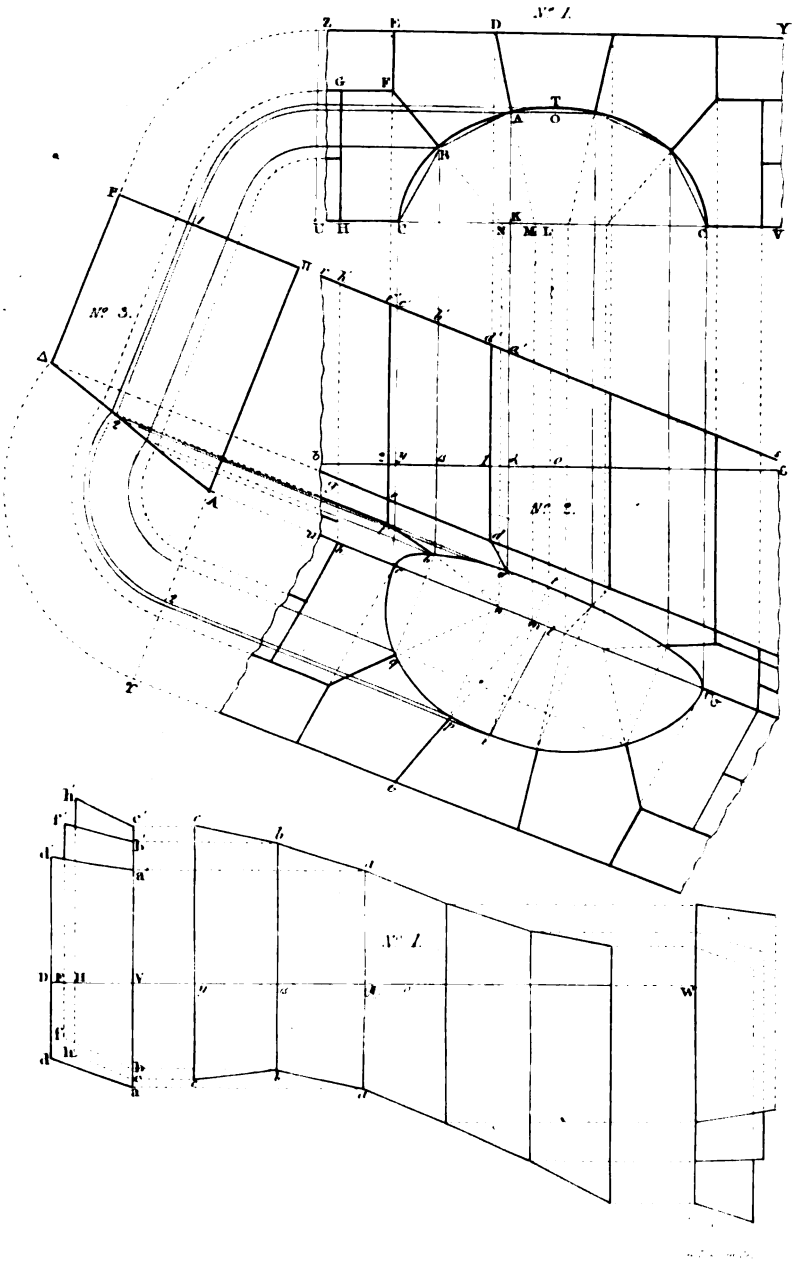


Fig. 3.

Fig. 4.




N° 1.
N° 3.
N° 2.
N° 1.

SECTION VI.

ON OBLIQUE ARCHES.

PROBLEM I.

To execute an oblique cylindroidic arch, intersecting each side of the wall in a semi-circle, the imposts of the arch being given.

Let *fig.* 1, *Plate* IX, be the elevation, and in *fig.* 2, let ABCD, EFGH, be the two imposts which are equal and similar parallelograms, having the sides AB, FE one of each in a straight line, and the sides DC and GH in a straight line.

Join GC, and on GC as a diameter, describe the semi-circle GIC, which, if conceived to be turned upon the line GC as an axis, until its plane become perpendicular to the seat BCGF of the soffit of the arch, it will be placed in its due position. Divide the semi-circular arc CIG into as many equal parts as the ring-stones are to be in number. We shall here suppose there are to be nine ring-stones. From the points of division, 1, 2, 3, &c. draw ordinates perpendicular to GC, meeting GC in the point *p*, *q*, *r*, &c. Perpendicular to CB, the jamb-line of the impost, draw the lines *p*1, *q*2, *r*3, &c.; from the point C as a centre, with the chord of one-ninth part of the semi-circular arc, CIG, describe an arc intersecting *p*1 CB at 1; from the point 1, with the same radius describe an arc intersecting the line *q*2, in the point 2; from the point 2 as a centre with the same radius, describe an arc intersecting the line *r*3, in the point 3; and so on. Join the point C and 1; 1 and 2; 2 and 3, &c. and thus form the entire edge CKL, of the devolopement of the semi-circular arc CIG.

Through the points 1, 2, 3, &c. in CKL, draw the lines 1β, 2γ, 3δ, &c, parallel to CB, and make 1β, 2γ, 3δ, &c. each equal to CB; and join Bβ, $\beta\gamma$, $\gamma\delta$ &c.; then CBβ1 is the soffit of the first ring-stone; 1$\beta\gamma$2, is the soffit of the second ring-stone; 2$\gamma\delta$3, the soffit of the third ring-stone, and so on.

Perpendicular to GF draw FJ; produce CB to J; and parallel to CJ, draw *ps*, *qt*, *ru*, &c. Intersecting FJ in the points *v*, *w*, *x*, &c., make *vs*, *wt*, *xu*, &c. respectively equal to *p*1, *q*2, *r*3, &c. Join J and *s*, *s* and *t*, *t* and *u*, &c.; and complete the polygonal line J*u*F. Through the points *s*, *t*, *u*, &c. draw the joint lines *sy*, *tz*, *uΘ*, radiating to the point *o*; then will the angles of inclination of the beds and soffits be N*Js*, *ys*J, the first ring-stone; *yst*, *zts*, for the second ring-stone; *ztu*, *Θut* for the third ring-stone; and so on.

From any point B in EC, *fig.* 3, make the angle CBA equal to the angle ABC, of the impost *fig.* 2. Prolong CB to E. From B as a centre, with any radius describe the semi-circular arc CDE; and on BC as a diameter, describe another semi-circular arc C*g*B. Divide the semi-circular arc CDE, in the points 1, 2, 3, &c. into nine equal parts, equal to the number of ring-stones, and draw the radials 1B, 2B, 3B, &c. intersecting the semi-circular arc C*g*B in the points *f*, *g*, *h*, &c. Draw CA perpendicular to BC; and in BA as a diameter, describe the same circular arc BCA. From the point B, with the radii B*f*, B*g*, B*h*, &c. describe the arcs *fi*, *gk*, *hl*, &c. meeting the semi-circular arc BCA, in the points *i*, *k*, *l*, &c., and draw the straight lines B*i*, B*k*, B*l*, &c. Then, ABC being the angle of the impost, AB*i* will be the angle of the joints at the junction of the first and

second ring-stones; AB*k* the angle of the joints at the junction of the second and third ring-stones; AB*l* will be the angle of the joints at the junction of the third and fourth ring-stones, &c.

To apply the moulds for cutting any one of the ring-stones, or to form the solid angles made by the face, the two beds and the soffit of the stone, which being done will form that ring-stone.—For instance, let it be required to form the third ring-stone:—We have given the plain angle $2_\gamma\delta$, figure 2, which is a side, and the plane angle AB*k* *fig.* 3, another adjacent side; also the angle *ztu*, *fig.* 2, which is the inclination of these two sides, to construct the solid angle. This can be easily done by working the bed of the stone corresponding to the joint 2_γ on the soffit *fig.* 2; then work the narrow side of the stone, from which the soffit is to be formed, first as a plane surface, making an angle *ztu*, with the bed first wrought; place the surface of the mould *abcd*, *fig.* 4, upon the narrow side of the stone, which is to form the soffit, so that the edge *ab* may be upon the arris of the stone; then by the edge *bc*, draw a line: again, upon the wrought side which is intended for the bed, apply the angle AB*k*, *fig.* 3, so that the line AB may be upon the arris, and the point B upon the same point that *b* was applied; then by the leg B*k*, which is supposed to be upon the surface of the bed, draw a line; we have only to cut away the superfluous stone on the outside of the two lines on the bed and on the soffit; and thus we shall form a complete trehedral; the plane soffit of the stone being gauged to its breadth, and the mould $2ed3$, *fig.* 1, being applied upon the last wrought side, so that the points *d*, *e*, may be upon the points of the stone to which *b* and *c* were applied; then drawing a line by the edge $d3$, and cutting away the superfluous stone between the two lines on the front, and on the plane of the soffit, will form the upper bed of the stone.

This will be made sufficiently evident by a developement of the soffit, the two beds, and the front of the ring-stone. Make an equal and similar parallelogram *abcd*, *fig.* 4, to that of $2_\gamma\delta3$, *fig.* 2. Make the angles *abe*, *dcg*, *fig.* 4, respectively equal to the angles AB*k*, AB*l*, *fig.* 3; then *bc* being equal to *de*, *fig.* 1, apply the mould $2de3$, so that the points *d*, *e* may be upon *bc*, *fig.* 4, and draw the front of the stone *bcki* *fig.* 4, and similarly draw *adml*. Make *be* equal to *bi*, *cg* equal to *ck*, and draw *ef* and *gh* parallel to *ba* or *cd*, and this will complete the developement.

A complete model of the stone will instantly be formed, by revolving the four sides *abef*, *bcki*, *cdhg*, *dalm*, upon the four lines *ba*, *bc*, *cd*, *da* as axes, until *e* coincide with *i*, *k* with *g*, *h* with *m*, and *l* with *f*.

We have here made use of the developement of the intrados in the construction of the solid angles, as being easily comprehended. The ring-stones might, however, have been formed by the angle of the joints, which is one side of a trehedral; one of the angles of the face mould, which is the other adjacent side; and the inclination of these two sides; so that we shall have here also two sides and the contained angle, to construct the solid angle of the trehedral. As an example, let it again be required to construct the third ring-stone. To find the angle which the face of the third ring-stone makes with the bed in the second joint: we have here given the two legs ABC, CB2, *fig.* 3, of a right-angled trehedral, to find the angle which the hypothenuse makes with the side CB2: this being found, will be the inclination of the face-mould, $2de3$, *fig.* 1, and AB*k*, *fig.* 3. Therefore, in this case work the bed of the stone first, then the face,

to the angle of inclination thus found. Upon the arris apply the leg AB of the joint-mould AB*k*, *fig.* 3, so that the side B*k* may be upon the bed, and draw a straight line on the bed by the edge B*k*; next apply the mould 2*d*e3, so that the arc *d*2 may be upon the arris, and the point *d* upon the same point of the arris to which the point B was applied, and the chord *de* upon the face; then draw a line on the face of the stone, by the leg *de*; and work off the superfluous stone, and the face will be exhibited. *Fig.* 5, shows the stone as wrought.

From what has been said, it is evident that if one of the solid angles of a ring-stone be formed of an oblique arch in a straight wall, the remaining solid angle may be formed without the use of the trehedral. Thus, for instance, suppose the solid angle which is formed be made by the surface of the soffit, the bed, and the face of the arch—we have only to guage the soffit to its breadth, and apply the head-mould upon the face of the stone; then by working off the superfluous stone between these lines, another solid angle will be formed by the surface of the soffit, the upper bed of the stone, and the face of the arch.

And since the angle of the joints is the same in the lower and upper beds of any two ring-stones that come in contact with each other, the same angle of the joints will do for both, so that in fact, if this be carried from one ring-stone to another, the arch may be executed without any joint mould.

This mode would, however, not only be inconvenient, but liable to very great inaccuracy. It would be inconvenient, as it is necessary to work one stone before another, so that only one workman could be employed in the construction of the arch. It would be liable to inaccuracy when the number of ring-stones are many, for then any small error would be liable to be multiplied or transmitted from one stone to another. Besides, it is satisfactory to have a mould to apply, in order to examine the work in its progress.

What has been now observed, with regard to the oblique arch in a straight wall, and with respect to the angle on the edges of the point, will apply to every arch of which the intrados is a cylindric or cylindroidic surface.

In the construction of any object it is always desirable to have two different methods, as one may always be a proof or check to the other. Besides, though these methods may be equally true in principle, one of them may be often liable to greater inaccuracy in its construction than the other.

PROBLEM II.

To construct the moulds for a cylindretic oblique arch terminating upon the face of a wall in a plane at oblique angles to the springing plane of the vault, so that the coursing joints may be in planes parallel to the ruller lines of the intrados of the vault.

Let the vertical plane of projection be perpendicular to the axis of the intrados, and it will therefore be also perpendicular to all the joints of which their planes are parallel to the axis: hence

The vertical projection of the intrados will be a curve equal and similar to the curve of the right section of the intrados.

The vertical projections of the coursing joints will be radiant straight lines, intersecting the curve lined projection of the intrados.

The vertical projections of all the joints which are in vertical planes parallel to the axis, will be straight lines perpendicular to the ground line.

The vertical projection of all the joints *m*, horizontal planes, will be straight lines parallel to the ground-line.

Moreover, the vertical projections of the intersections of planes which are parallel to the axis will be points.

The horizontal projections of the planes of the coursing joints, and of all the intersections of the planes of all joints which are parallel to the axis, will be straight lines perpendicular to the ground-line.

And because the axis of the archant is perpendicular to the vertical plane, the vertical projections of the intrados, and of the joints which are parallel to the axis, will have the same position to one another, as the curve and other lines in the right section which are formed by the joints in planes parallel to the axis.

All sections which are perpendicular to the horizon, will have straight lines for their horizontal projections.

The length of any inclined line will be to the length of its projection, as the radius is to the cosine of the line's inclination to the plane of projection.

We shall suppose that the stones which constitute the intrados of the archant, have not fewer than three, nor more than four, of their faces that intersect the intrados. The stones which form the face of the archant, when they do not reach the rear of the vault, have three of their faces which intersect the intrados, and three at least which intersect the face.

We shall call all these surfaces which intersect the intrados or face of the archant, *the retreating sides of joints of the stones;* and the surface of any stone which forms a part of the intrados, the douelle of the stone.

When the stones do not reach from the front to the rear of the intrados of an archant, they are arranged in rows, in such a manner, that the stones which constitute any one of the rows, have as many of their retreating sides as there are stones in the row, in one continued surface, and the opposite retreating sides of all the stones in another continued surface, while the heads form a portion of the intrados extending from front to rear of the vault, and the remaining retreating sides of the stones either come in contact, or are connected together by mortar.

Every such row of stones is called *a course of vaulting.*

One course may be joined to another by bringing their adjacent continued surfaces in contact; but they are generally cemented with mortar, which is called *the coursing joint*, and as this cementing substance should be as thin as possible, and of an equal thickness, we shall suppose that the coursing joints intersect the intrados in lines, extending from front to rear of the vault, we shall call these lines the *coursing lines of the intrados.*

In this example, as the vertical projection of the intrados, and of the joints which are in planes parallel to the axis, are identical in all respects to the lines of the right section, the dimensions between every two corresponding points being equal in both, we may therefore substitute at once the right section for the vertical projection, placing the right section upon the ground-line UV.

Plate X. Let No. 1 be the right section placed in the situation of the vertical plane projection upon the ground-line UV, the curve-line COC′ being the vertical projection of the intrados, AD, BF, CH, the projections of the vertical projection coursing joints, meeting the projection of the intrados in the points A, B, C. Of these radiant lines CH is the projection of the springing. The line BF meets the line FG parallel, and EF perpendicular to the ground-line UV. The

extrados ZEDY of this section is a straight line parallel to the ground-line. As this right section of this vault is symmetrical, we shall only describe one half, the other will be understood by the same rules.

Let *rs*, No. 2, be the trace of the vertical face of the wall on the horizontal plane of projection, making a given angle with the ground-line UV, and let *uv* and *rs* be the traces of the inclined face of the wall; the inclination of this face being given by a right section of the wall.

Let ΓΔΔΠ, No. 3, be the right section of the wall, of which ΔΠ, the base, is equal to the shortest distance between the two traces *uv* and *rs*, No. 2, of the faces of the wall. The line ΠΓ of this section, is the section of the vertical face, and ΔΔ, that of the inclined face of the wall.

This section ΓΔΔΠ, No. 3, is so situated, that the base line ΔΠ is perpendicular to the traces *uv*, *rs*, of the faces of the wall, No. 2, the point Π being in the line *rs* or *sr* prolonged, therefore the point Δ in the line *uv*, or *vu* prolonged, and Π′ being perpendicular to ΔΠ will be in the same straight line with the horizontal trace *rs* of the vertical face of the wall.

In order to obtain the projection of the intersection of the intrados and of the joints which are in planes parallel to the axis of the intrados with the inclined face of the wall; we must find the projection of every line in this inclined face made by the intersection of a horizontal plane passing through every point in the right section which is formed by every two lines in its construction.

For this purpose it will be necessary to find the horizontal projection of every point of the lines where the intersections of the planes parallel to the axis meet the inclined face of the wall. To proceed:—

Take all the heights of the points of the right section, and apply them respectively from the point Π in the line ΠΓ No. 3; through these points draw lines parallel to ΔΠ, so that each line may meet the sloping line ΔΔ. From each of the points in the line ΔΔ draw lines parallel to the horizontal trace *uv*, No. 2, and lines being drawn from the corresponding points of the right section will give the points required by the intersection of the two systems of parallel lines.

Thus to find the horizontal projection of the intersection of any particular line which is parallel to the axis with the inclined face of the wall, this line being given by its intersecting point in the right section, No. 1; this point being the intersection of one of the coursing lines, viz. the first A from the middle of the section, No. 1.

Draw A*a* perpendicular to the ground-line, and transfer the height KA of the point A, No. 1, upon the line ΠΓ, No. 3, from II to 1. Draw 1-2 parallel to IIΔ, ΔΔ meeting PQ in 2. From 2 draw 2*a* parallel to either of the horizontal traces *uv*, or *rs*, No. 2, and the point *a* (No. 2) is the horizontal projection of the extremity of the coursing line of the intrados which passes through the point A of the right section.

In the same manner may be found the projections *b* and *c* of the intersections of the coursing joints of the intrados, with the face of the archant, and also those of the intersections of the planes parallel to the axis: the projections of these points being exhibited by Italic letters corresponding to those of the Roman in the right section.

To find the developement of the intrados or soffit of the arch.

Parallel to the ground-line in No. 2, draw the regulating line δ_1 in the horizontal plane of projection, intersecting the projections *aa′*, *bb′*, *cc′*, &c. of the coursing joint-lines in the points *a*, β, γ, &c.

In any convenient situation, No. 4, draw the line VW, and in VW take any convenient point *o*. In *o*V make *oa* equal to OA, No. 1, the half-chord of the arc of the section of the key-course; and in No. 4, make $a\beta$, $\beta\gamma$, &c. equal to the succeeding chords AB, BC, &c. No. 1, of the sections of the courses in intrados.

Through the points *a*, β, γ, No. 4, draw the lines *aa'*, *bb'*, *cc'*, perpendicular to VW, and make *aa*, βb, γc, respectively equal to *aa*, βb, γc, No. 2, as also *aa'*, $\beta b'$, $\gamma' c$, No. 4, equal to *aa'*, $\beta b'$, $\gamma c'$, No. 2. In No. 4, join *ab*, *bc*, on the one side, and *a'b'*, *b'c'*, on the other; then *aa' b'b*, *bb' c'c*, will be the chord-planes of the soffits of the courses of the stones on each side of the key-course. The figures of the chord-planes of the right-hand side of the arch being found in the same manner, will give the entire developement of the intrados by joining the corresponding ends of the chord-plane of the key-course.

Through any convenient point V, No. 4, in the line VW, draw ac' perpendicular to VW, and prolong WV to D. Make VD equal to AD, No. 1, and through D, No. 4, draw dd' parallel to ac. In ac, No. 4, make Va, Va', respectively equal to *aa*, *aa'*, No. 2, and make Dd, Dd', No. 4, respectively equal to 1*d*, 1*d'*, No. 2. Join ad, ad', then will aa' d'd, No. 4, be the side or figure of the coursing joint corresponding with the line AD, No. 1. In the same manner the remaining figures bb'f'f, cc'h'h, will be found, as also the remaining figures of the coursing-joints on the right-hand side.

Then the figures of the moulds for the course of stones, of which the right section is a figure equal and similar to ABFED, No. 1, are No. 1, and *aa'b'b*, aa'd'd, bb'f'f, No. 4. All the stones are wrought to the form of right prisms before the heads in the front and rear of the arch are formed, then the moulds of the upper and lower beds are applied, and their figures are drawn upon the surfaces of the coursing-joints, so as to give the intersections of the coursing-joints with the face of the arch.

In the course of stones, on the left hand next to the key-course *aa'b'b*, No. 4, is the chord-figure of the intrados, aa'd'd, No. 4, the upper-bed, and bb'f'f the lower bed.

To find any point in the oblique face of the arch. Let the point to be found be the point corresponding to the point A.

The place of the point A in the oblique line AΔ, No. 3, is at the point 2, and its place upon the projection No. 2, is at *a*. Draw AT, perpendicular to A*v*, or to *uv*, and in AT make A2, equal to A2 in AΔ. From the point 2, in AT, draw 2*p* parallel to *uv*, and draw *ap* perpendicular to *uv*, and the point *p* will be in the curve of the oblique face of the arch.

In the same manner will be found the points *i*, *q*, &c. in the curve of the oblique face of the arch, as also all other points, by first finding their projections as at No. 2, and the heights of these points upon the oblique line AΔ, No. 3, and then transferring the points thus found upon the perpendicular AT. Through the points found in the perpendicular AT, draw lines parallel to *uv*, to intersect with lines drawn perpendicular to *uv* from the projections of the points to be found in No. 2, and the points of intersection of every two lines will be the points in the oblique face of the arch, corresponding to those in the section, No. 1.

The curve thus found in the oblique face of the arch will be an oblique curve; therefore the line *uv* will not be an axis, but a diameter.

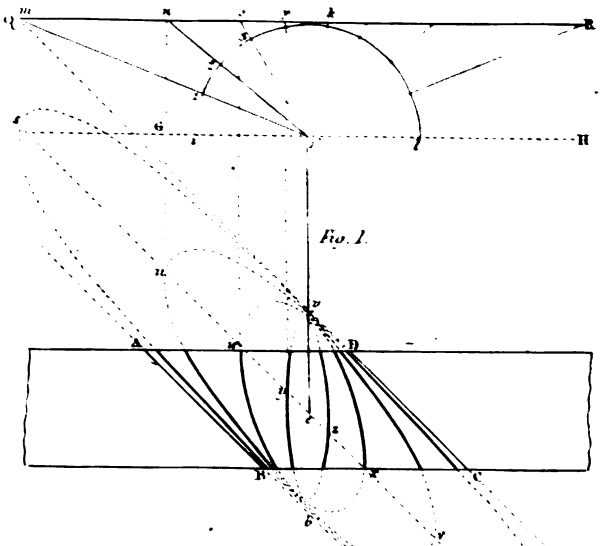


Fig. 1.

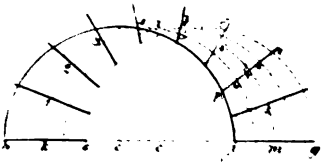
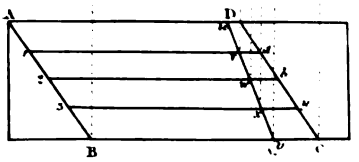


Fig. 2.



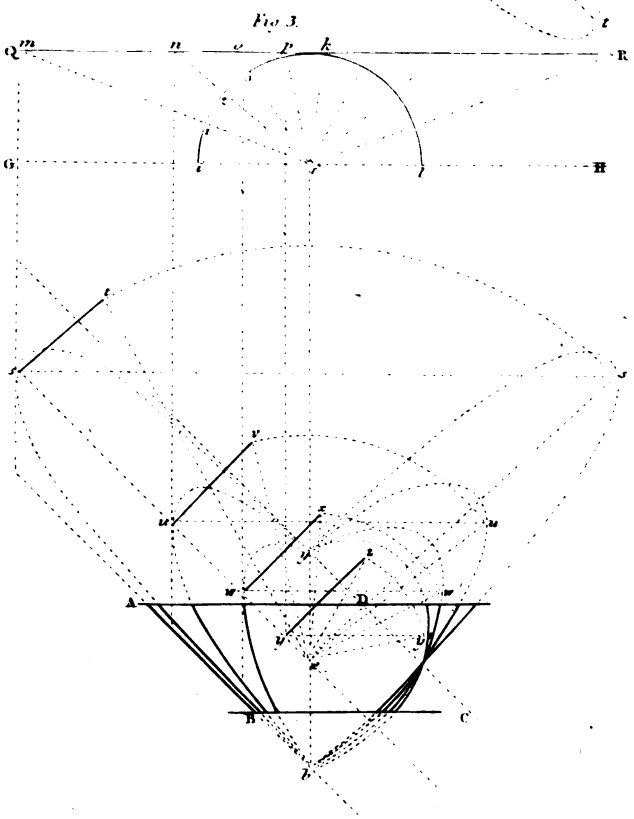


Fig. 3.

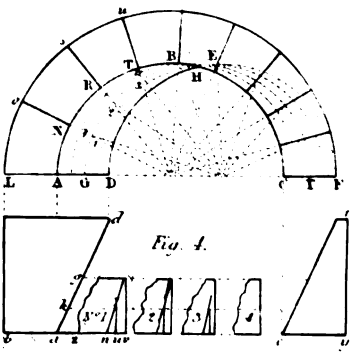
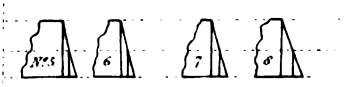


Fig. 4.



To find the direction of any joint in the oblique face of the arch, the plane of the joint being perpendicular to the springing plane of the arch.

Suppose, for instance, the plane passing through LT in the elevation, No. 1, perpendicular to UV. Find the projection *t* and *l* in the horizontal plane of projection of the points represented by T and L in the vertical plane of projection, and find the point *i* in the curve of the oblique face of the arch, corresponding to the point T in the vertical plane of projection; then joining the points *l* and *i*, the straight line *li* will be the position of the joint in a plane perpendicular to the springing plane of the intrados of the arch.

PROBLEM III.

To construct an oblique arch for a canal with a cylindric intrados, so that the sides of the coursing joints may be in planes which intersect each other in straight lines perpendicular to the two faces of the arch, and parallel to the horizon, and that the planes of the coursing joints may make equal angles with each other :—

Plate IX. *fig.* 1. Let ABCD be the plane of the arch; AD and BC being the planes of the faces, and AB, DC, the plans of the springing lines of the intrados of the arch parallel to the line of direction of the canal.

Find the middle point *e* of the parallelogram ABCD, and draw *ef* perpendicular to AD or BC. Through any convenient point *f* in *ef* draw GH perpendicular to *ef*, and from the point *f* with a radius equal to half of AD or BC, describe the semi-circumference *ikl* meeting GH in *i* and *l*. Divide the circumference *ikl* from *i* into as many equal parts as the coursing joints are intended to be in number: for example, let it be divided into nine equal parts, 11, 12, 23, &c. Draw the tangent QR parallel to GH, and from *f*, and through the points 1, 2, 3, &c. of division, draw the straight lines, *fm*, *fn*, *fo*, *fp*, &c. meeting QR in the points *m*, *n*, *o*, *p*.

Through *e* draw *st* parallel to AB or DC, and draw *ms*, *nu*, *ow*, *py*, perpendicular to GH, meeting *st* in the points *s*, *u*, *w*, *y*. Make *ez*, *ex*, *ev*, *et*, equal respectively to *ey*, *ew*, *eu*, *et*. Prolong CD to meet *ef* in γ, and prolong *fe* and AB to meet each other in the point β; then with the two diameters *st* and $\beta\gamma$ describe the ellipse $s\beta t\gamma$, and with the two diameters *uv* and $\beta\gamma$ describe the ellipse $u\beta v\gamma$, and so on; then the portions of these curves comprised between the lines AD and BC, will be the plans of the coursing joints.

The method which has now been shown for finding the joint lines of the intrados of the arch is quite satisfactory as to the principle, since it exhibits the plans of the complete sections of the cylinder by the cutting planes of the joints to the several angles of inclination. We shall show how the joint lines of the intrados themselves may be found, as depending upon the plans of the joints.

To find the plane curves for the joints of the intrados :

Having found the conjugate diameter $\beta\gamma$, and the semi-conjugate *es*, as also the semi-conjugate diameter *eu*, *ew*, *ey*, *Plate* IX. *fig.* 3, as has been shown in the immediately preceding plate, proceed in the following manner. Draw *st*, *uv*, *wx*, *yz*, perpendicular to *es*, and make *st*, *uv*, *wx*, *yz*, each equal to the radius of the semi-circle *ikl*. Join *et*, *ev*, *ex*, *ez*. Draw *ss'*, *uu'*, *ww'*, *yy'*, perpendicular to $\beta\gamma$ or

βf; and from the point e as a centre, with the radii et, ev, ex, ez, describe the arcs ts', vu', xw', zy'. Join es', eu', ew', ey'.

With the diameters es', eu', ew', ey', and with their common conjugate $\beta\gamma$, describe the semi-ellipsis $\beta s'\gamma$, $\beta u'\gamma$, $\beta w'\gamma$, $\beta y'\gamma$, &c. then the portions of these curves contained between the lines BC and AD will be the curve lines of the joints required.

Let ABCD, *fig.* 2, be the plan, which is a parallelogram as before. Divide AB into any number of equal parts, as, for example, into four, at the points 1, 2, 3, and draw the lines 1α, 2β, 3γ, parallel to BC or AD, meeting DC in the points α, β, γ, and let hg be the ground-line of the elevation; then AD, 1α, 2β, 3γ, BC, are the plans of semi-circular sections of the intrados, and are each parallel to the ground-line hg, the elevations of these plans will be semi-circles.

These elevations being described, let efg be the elevation to the plan BC, klm the elevation to the plan 2β in the middle, between the plans BC and AD of the semi-circular sections of the cylinder. Let c be the centre of the semi-circular arc klm, and divide the semi-circular arc klm into as many equal parts as there are intended to be courses in the arch; for example, let the number of courses be nine, and therefore the semi-circular arc klm must be divided into nine equal parts, in the points 1, 2, 3, &c.

From the centre c, &c. and through the points of division 1, 2, 3, draw lines which will be the elevation of the joints, and let pt be one of these lines, intersecting the five semi-circles in the points p, q, r, s, t. Draw the lines pu, qv, rw, sx, ty, perpendicular to the ground-line hg, intersecting the plans AD, 1α, 2β, 3γ, BC, in the points u, v, w, x, y, and the line $uvwxy$ being drawn, will be the correct plan of the joint required.

In the same manner the plans of the remaining joints may be found.

Let *lad fig.* 4, be the plan of one pier, and ycf the plan of the other pier, ad and cf being the plans or horizontal sections of the springing lines of the intrados; also, let LF be the ground-line parallel to the planes of the front and rear elevations. Describe the five semi-circles in the elevation as before, ABC being that in the front, DEF that in the rear, and GHI that belonging to the middle section.

Divide the semi-circular arc GHI into the number of equal parts required, and let the points of division be 1, 2, 3, &c. Through the points 1, 2, 3, &c. draw the straight lines 1o, 2s, 3U, &c. radiating to the centre of the semi-circular arc ABC′ intersecting the curve ABC in the points N, R, T, and the lines NO, RS, TU, will be the joint lines of the face, and will be perpendicular to the curve line ABC.

In the straight line ac, which is the plan of the face of the arc, take a part zn for the joint in the direction NO of the elevation, and let the lines 1N, 2R, 3T, intersect the semi-circular arc between the parallel sections ABC and DEF in the points α, β, γ, &c. Let the points u and v be in the straight line ac. Make nu and uv respectively equal to Nα, α1, and draw uw and vx perpendicular to zv.

Divide ad into as many equal parts as the thickness of the arch is divided into equal parts by the planes of the semi-circular arcs which are parallel to the planes of the front and rear faces; that is, divide ad into four equal parts, and let ak, ag, be two of those parts in succession, and draw kw and gx parallel to ac; then, n, w, x, will be three points in the curve, which is the intersection of the plane of the curving joint and the cylindric surface forming the intrados; and

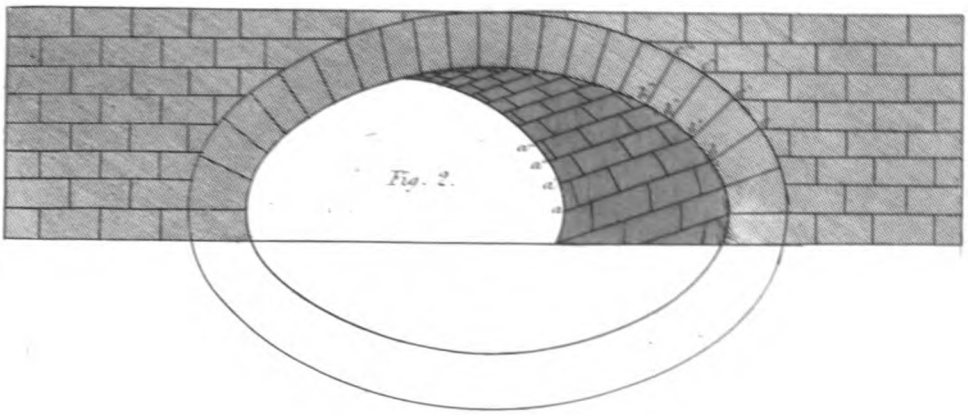


Fig. 2.

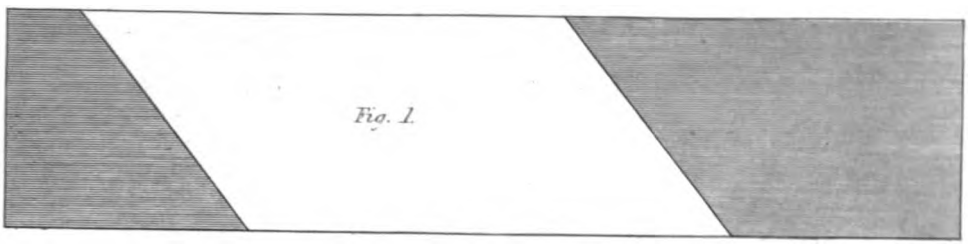


Fig. 1.

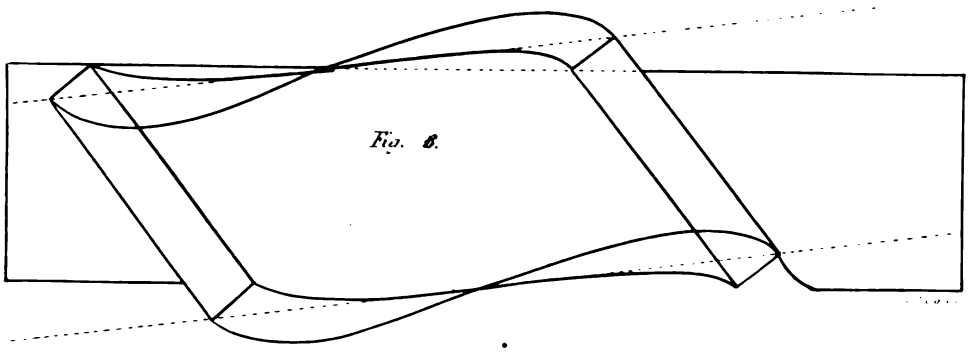


Fig. 6.

thus we might find as many points as we please, by increasing the number of equi-distant sections. This gives the first joint next in succession to the springing AD.

In the same manner all the other coursing joints will be found as at No. 2, No. 3, No. 4, &c.

Observations on the preceding methods :—

The most simple construction of an oblique arch with a cylindrical intrados, is that where the sides of the coursing joint are in planes intersecting the intrados perpendicularly in straight lines, as in the first example; but when the arch is very oblique, the coursing joints intersect the planes of the two vertical faces in very oblique angles.

It has been shown that when the sides of the coursing joints are in planes perpendicular to the front and rear faces, these planes cut the intrados very obliquely, except at the middle section, or in the best method in the curve of the front and rear. It therefore appears, that in an oblique arch, in order that the surfaces of the coursing joints may intersect both the intrados, and the face of the arch perpendicularly, the sides of the coursing joints cannot be in planes.

In order that every arch may be the strongest possible, a straight line passing through any point of the surface of a joint perpendicularly to the intrados, ought to have all its intermediate points between the point through which it passes, and the intrados, in the surface of the side of the coursing joint; and in order that the stones may be reduced to their form in the easiest manner possible, the surfaces should be uniform; and the forms of the stones should be similar solids, and the solids similarly situated.

To obtain these desirable objects will not be possible where the faces of the arch are plane surfaces; however, even in this case, the joints may be so formed by uniform helical surfaces, that they will intersect the intrados perpendicularly in every point, and the faces of the arch perpendicularly in two points of the curve.

This mode of executing a bridge renders the construction much stronger than when the joints of it are parallel to the horizon. Since in this last case, the angles of the beds and the faces are so acute upon one side, that the points of the ring-stones are very liable to be broken, or even to be fractured in large masses.

For, though the gravitating force acts perpendicularly to the horizon; yet, notwithstanding, when one body presses upon the surface of another, the faces act upon each other in straight lines perpendicularly to their surfaces. Hence a right-angled solid will resist equally upon all points of its surface.

From this consideration, we are induced to give a preference to the construction with spiral joints, though attended with greater difficulty in the execution.

PROBLEM IV.

To execute a bridge upon an oblique plan, with spiral joints rising nearly perpendicular to the plane of the sides.

Fig. 1, *Plate* XII., is the plan of a bevel bridge; *fig.* 2, the elevation of the same, as the two faces of the obtuse angle are shown; the joints of the intrados descend from the face of the arch in such a manner, that supposing the lines *ab*

joints *ba*, *b' a'*, *b'' a''*, &c. are as nearly perpendicular to the curve *bb'b''b'''* as possible for the construction to admit of, supposing the joints to be all parallel to each other. By making the joints of the intrados all parallel to each other, all the intermediate arch-stones will have the same section when cut by a plane at right angles to the arris-line of the bed and intrados of the arch; therefore, if the intermediate arch-stones are equal in length, the upper and lower beds must be the same winding surfaces, and consequently must all coincide with each other, and all the end-joints must be equal and similar surfaces, and thus all the arch-stones may be equal and similar bodies.

The most considerable obliquity of the joints in the intrados is at those two parts of the curve where it meets the horizon. The obliquity of the intradosal joints, at the crown of the arch, is considerably less than at the horizon; but in the middle of that portion of the curve, between the crown and the horizon on each side, the intradosal joints are exactly perpendicular to the horizon.

Had it not been for these deviations, the execution of this arch would have been extremely easy, and very few constructive lines would have been necessary.

This arch, however, might be executed so that all the intradosal joints would be perpendicular to the curve-line of the face and intrados; but this position would have caused such a diversity in the form of the stones as to increase the labor in a very great degree, and, consequently, to render the execution very expensive; and not only so, but as the joints would have been out of a parallel, their effect would have been very unsightly. A succession of equal figures, similarly formed, has a most imposing effect on the eye of the spectator. The laws of perspective produce on the imagination a most fascinating variety, the figure only varying by imperceptible degrees, which yet in the remote parts produces a great change.

There is still another method in which the greater part of the difficulty may be removed without impairing the strength of the arch; this manner is to form the ring-stones so that the joints in the intrados may be perpendicular to the curve forming its edge; the intermediate portion of the intrados to be filled in with arch-stones, which have their soffit-joints parallel to the horizon. This disposition of the joints might not be so pleasant to the eye, but, if well executed, it could not be disagreeable.

If the ends were made to form spirals, as in *fig.* 3, and a wall erected above the arch, as this wall could only be made to coincide in three points at most with the face of the arch, no regular form of work could be introduced so as to connect the wall to the ring-stones.

To form the developement of the intrados of the oblique arch, with spiral or winding joints, and thence to find the plan of the developement or intrados.

Let AC, *Plate* XIII., be the inner diameter of the face of the ring-stones; upon AC describe the semi-circular arc ABC, and find its developement upon the straight line AD. Draw the straight lines AG and DI perpendicular to AD.

In AG take any point M, and draw ML, making the angle AML equal to the angle of the bevel of the bridge, meeting CH in the point L. Draw L*a* perpendicular to AG', meeting AG in *a*. Prolong L*a* to meet DI in Q, and draw ON

section of the face of the arch and intrados in the points b', b', b', &c. then the $a'b'$, $a''b''$, *fig.* 1, to be the joints of the intrados, meeting the curve of the inter-parallel to LM, so that the distance between LM and ON may comprise the breadth of the bridge. Let ON meet CH in O, and AG in N; then will LMNO be the plan of the bridge. Find the developement MPQSRN upon the straight line AG′, the curve MPQ being the developement of the arc insisting on ML, and NRS the developement of the curve line upon NO.

Draw MQ, and divide MQ into as many equal parts as there are intended to be arch-stones, which we shall here suppose to be fifteen; hence there will be a ring-stone in the middle, and the number of ring-stones will be equal on each side of the middle one; let P be the middle point of the line MQ, and let a, b, c, &c. be the points of division on one side of P, and a, b, c, &c. the points of division on the other side.

Through the middle point P draw the straight line WX. Through the points a, b, c, &c. draw the lines do, ep, fq, &c. parallel to WX, meeting the curve MQ in the points k, l, m, &c. and the curve NS in the points o, p, q, &c.; also through the points a', b', c', &c. draw the lines $d'o'$, $e'f'$, $p'q'$, &c. parallel to WX, meeting the curve MQ in the points k', l', m', &c., and the curve NS in the points o', p', q', &c.; then ao, lp, mq, &c.; also $a'o'$, $l'p'$, $m'q''$, &c. will be the joint lines on the intrados of the arch; the heading joints are marked on the developement at right angles to these joints.

Now as all the intermediate arch-stones are equal and similar, it will only be necessary to show how one of the stones may be formed. For this purpose, let *uvwx* be the developement of the soffit. Draw *vy* parallel to MN or QS. Run a straight draught *vy* diagonally upon the intrados of the stone, making an angle *uyv* with the edge *uy*, or *ux*, of the soffit. Draw *ua* and *w* perpendicular to *vy*.

Make two moulds Z,Z to the arc ABC, so that their chords may be equal; then cut two draughts *ua* and *wv* so as to coincide with the convex edges of the two moulds Z,Z, while the straight edges of the two moulds Z,Z are out of winding.

That is, apply the moulds Z,Z at the same time; the one upon the line *ua* and the other upon the line *wa*, and sink a cavity or draught under each line; so that, after one or more trials, the convex edge may coincide with the bottom of each draught; and that the point marked upon each circular edge may coincide with the bottom of the draught *vy*; and that the two chord-lines of each circular mould may be in the same plane, that is, in workman's terms, out of winding or out of twist.

The remaining superfluous part may be worked off as directed by two straight edges, and thus the cylindric surface of the soffit of the stone will be formed.

The longitudinal spiral joints may be formed by means of the bevel at Y, where it is applied to the section of one of the arch-stones: but before the heading joints and beds are wrought, a pliable or flexible mould *uvwx* must be made, and bent to the convexity of the surface, so that the line *vy* may coincide with the bottom of the straight draught first wrought.

In applying the mould Y, the curve edge must be laid along the line *ua* or *av*; and in directions parallel to these lines; and several draughts must be wrought in the spiral bed, so as to coincide with the straight edge, and the angular with the line *vw*, or *ux*.

Having shown the developement of the intrados and its projection, it will be proper to show how the curves are projected.

Let the line AF, *Plate* XIV, the edge of the triangle AEF, be the developement of one of the longitudinal joints, and let HG at right angles to AF be the developement of one of the lines of direction of the heading joints ; then, as the projection of all the longitudinal lines is equal and similar, and the projection of the heading joints is equal and similar, one curve of each being obtained, and a mould formed thereto, each series of curves may be drawn by means of its proper mould.

Divide the arc ABC into any number of equal parts at the points 1, 2, 3, &c. and the straight line AF into the same number of equal parts at the points 1, 2, 3, &c.; but it will be most convenient to divide each into as many equal parts as the ring-stones are in number, which in this example are fifteen. From the points 1, 2, 3, &c. of division in the straight line AF, draw 1*a*, 2*b*, 3*c*, &c. perpendicular to AE, and through the points 1, 2, 3, &c. in the arc CB, draw lines 1*a*, 2*b*, 3*c*, &c., parallel to CD, and through the points *a*, *b*, *c*, &c. draw a curve, which is the projection of a cylindric spiral, and is the plan of one of the longitudinal joints required. In the same manner, dividing HG into the same number of equal parts as the arc ABC, and drawing lines as before from the divisions of the arc, and from the divisions of the straight line HG, to intersect each other respectively in the points *a*, *b*, *c*, &c. we shall have the curve of direction of the heading joints. In order to find the direction of the curve in the middle, it will be necessary to show the manner of finding a tangent in the middle of the curve. For this purpose,

Make the angle EA*k*, equal to EAF, and let the point *m* be the middle of the curve D*m*A. Through the point *m* draw *pg* parallel to *k*A, and *pg* will be the tangent required.

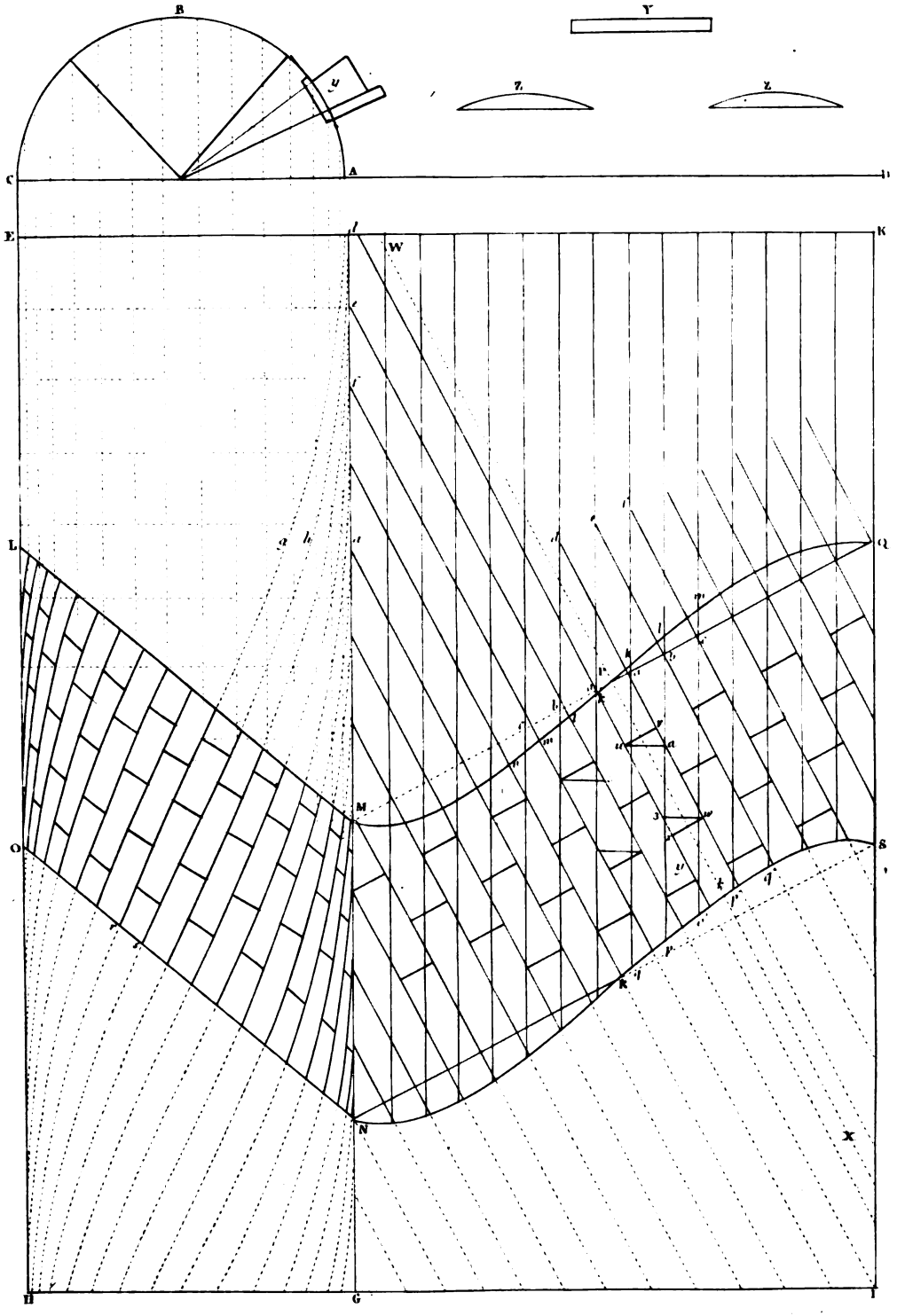
In like manner, make the angle AH*f* equal to AHG, and let *g* be the middle point of the curve H*g*C; through *g* draw *rs* parallel to H*f*, and *rs* will be a tangent to the curve H*g*C.

It is here evident from the tangents, that if these two curves had intersected each other in the middle, they would have been at right angles to each other; they are, however, still the projections of two straight lines bent upon the cylindric surface.

To draw a tangent to the point *n*. Draw *n*4 parallel to EA, meeting the curve AB in 4. Draw 4*u* perpendicular to the radical line, and make 4*u* equal to the developement of the arc 4A. Draw *ut* perpendicular to AG, and join *tn*, which is the tangent required.

To find the curvature of a stone along the two edges of the longitudinal joints, and along the heading joints of the intrados. In *fig.* 1, *Plate* XV, which is a developement of the intrados, *abcd* is the developement of the intrados of an arch-stone, it is required to find the curvature along *bc*, and *ad*, also in the direction *ab*, *dc* at the ends.

In *fig.* 2, make OA equal to the radius of the cylinder, and through A draw BE perpendicular to AO. Make the angle BOA equal to the complement of the angle with the joints in the developement of the intrados made with the springing lines, that is equal to the angle DAE, *fig.* 1. Make OC, *fig.* 2, equal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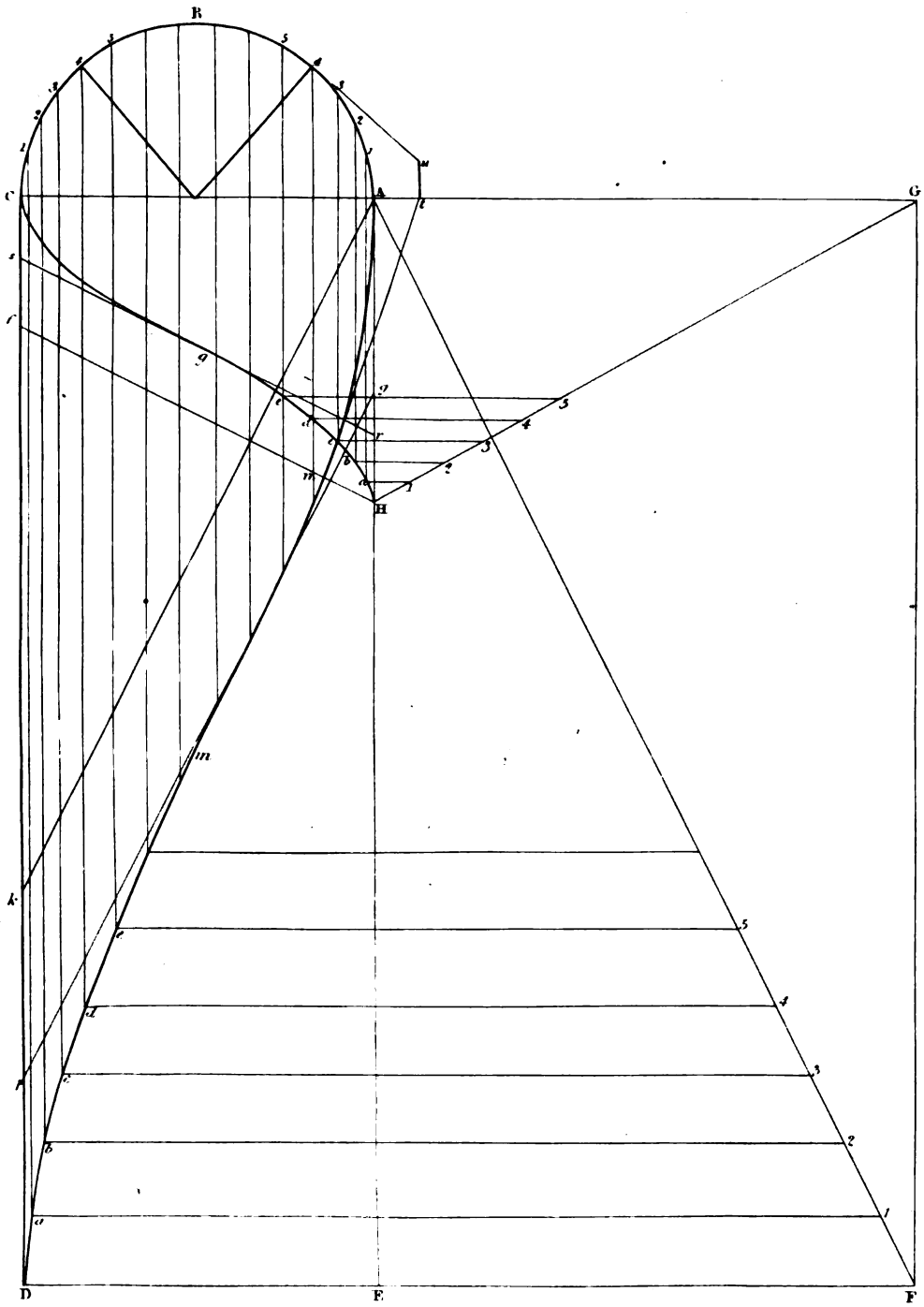
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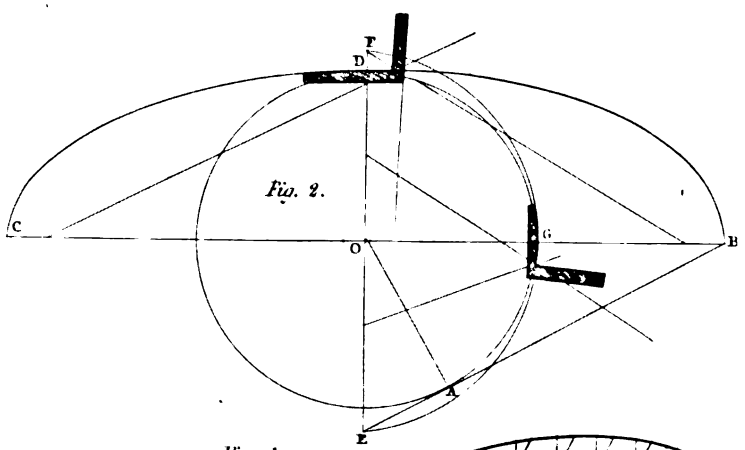

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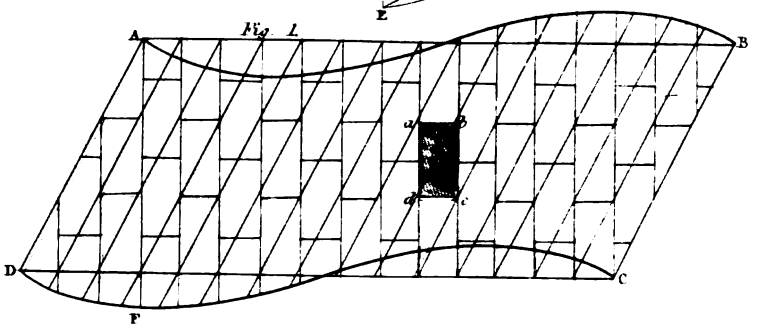

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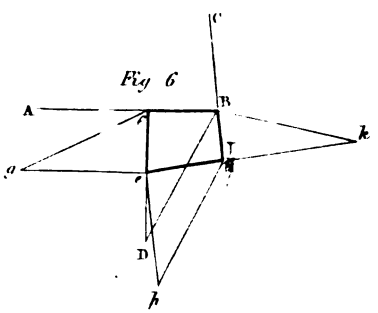


Fig 6

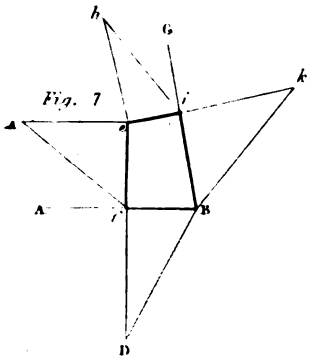


Fig. 7

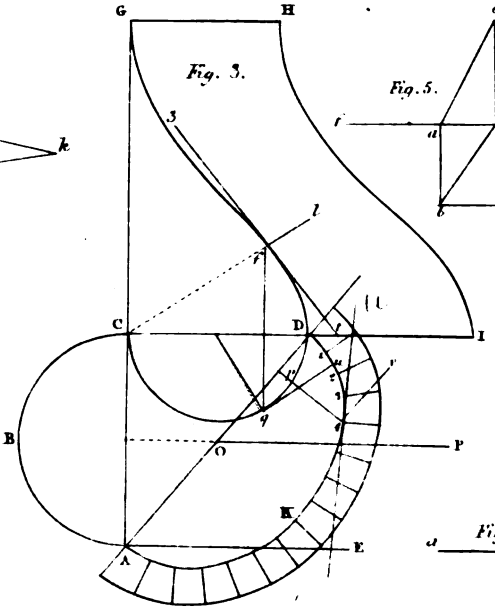


Fig. 3.

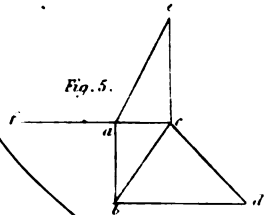


Fig. 5.

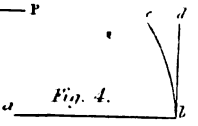


Fig. 4.

to OB, and draw OD perpendicular to BC. Make OD equal to OA. Then with the transverse axis BC, and semi-conjugate OD, describe the semi-elliptic arc or curve CDB; then the portion of the elliptic arc on each side of the point D will be the curvature in *fig.* 1, along the longitudinal edge *bc* or *da* of the soffit of a stone.

Again, produce DO to E, and made OE equal to OD. In OB, take OG, equal to OA, the radius of the circular end of the cylinder; then with the transverse axis BE, and the semi-conjugate OG, describe the semi-elliptic arc DGE, and the small portion of this arc on each side of the point G has the same curvature as *ab* or *dc*, *fig.* 1. Therefore, the stone being wrought hollow, as directed in the description of the preceding plate, then the mould shown at D is that for working the longitudinal joints, or those which terminate on the soffit in the lines *ad* and *bc*. In like manner, the mould G is that for working the heading joints which terminate upon the soffit in the lines *ab*, *dc*, &c. It will hardly be necessary to remind the reader, that the convex edge of the squares at D and G is to be applied upon the hollow soffit already wrought. The curvature of these moulds may be shown by calculation thus: let R be the radius of curvature, a = the semi-transverse axis, and b = the semi-conjugate; then $b : a :: a :$

$$R = \frac{a^2}{b}.$$

As for example to this formula, let the radius of the cylindric intrados, or $b = 13$ feet, and the semi-transverse axis, or $a = 28$ feet

28
28
224
56
13)784(60 feet 4 inches nearly
78
4
12
48

To find the angle of the joints of the face of the arch, and intrados of the oblique arch with spiral joints.

Let the semi-circular arc ABC, *Fig.* 3, be a section of the intrados at right angles to the axis of the cylinder. Draw CD and AE perpendicular to the diameter AC. Draw AD, making an angle with CD, equal to the inclination which the plane of the face of the arch makes with the vertical plane which is parallel to the axis of the cylinder, and which passes through the springing line of the arch.

Find the edge D*f*G of the developement and face of the arch, or draw the curve D*f*G with a mould made from the developement before shown. Draw the face of the ring-stones AKD. Let it now be required to find the fourth from the point D. Make D*f* equal to the portion D4 of the intrados AKD. Draw *fl* the developement of a part of the longitudinal spiral joint corresponding to the point 4 of the elliptic arc AKD. Draw the line *k* a tangent to the curve at *f*. To do this, we shall again repeat the process of which the principle has already

been taught, viz. On CD, as a diameter, describe the semi-circle C*q*D, and draw *fq*, intersecting CD perpendicularly. Draw *qu* a tangent to the semi-circular arc at the point *q*, and make *qu* equal to the developement of the portion *q*D of the semi-circular arc. Draw *ut* perpendicular to CD, meeting CD, or CD produced in the point *t*. Through *f* draw the straight line *ts*, and *ts* will be a tangent to the curve at the point. By this means we have the angles which the spiral joints in the intrados make at the point 4 with the elliptic curve AKD.

To find the angle made by the normal and the curve, in *fig.* 4.

In *fig.* 4, draw the straight line *ab*, and make *ab* equal to the radius of curvature of the elliptic arc AKD at the point 4. This radius would be near enough to make it the half of the half sum of the semi-parameters of the two axes.

But if greater nicety is required, let the radius of curvature be denoted by *u*, the semi-transverse axis OD or OA be denoted by *a*, and the semi-conjugate, which is the radius of the semi-circular arc ABC, be denoted by *b*, and let the distance O*p* be denoted by *x*; then will $r = \left\{ \frac{a^4 - (a^2 - b^2)x^2}{a^4 b} \right\}^{\frac{1}{2}}$ which will be exact to the number of figures found in the operation here indicated.

Having thus found the radius of curvature, either mechanically or by calculation, make *ab*, *fig.* 4, equal to that radius. From the point *a* as a centre, with the distance *ab*, describe the arc *bc*; and draw the straight line *bd* a tangent to the curve.

To find the angle made by a tangent plane to the cylindric surface at the point 4, *fig.* 3, and the plane of the face of the arch.

Draw the straight line 4*u* a tangent to the elliptic curve AKD at the point 4, and draw 4*v* parallel to AD. Trasnsfer the angle *u*4*v* to *abc*, *fig.* 5.

In *fig.* 5, at the point *b*, in the straight line *bc*, make the angle *cbd* equal to the angle DOP, *fig.* 3, which the axis makes with the plane of the face of the arch. Again in *fig.* 5, draw *cf* perpendicular to *ab*, intersecting *ab* in the point *a*. Draw *cd* perpendicular to *cb*, and *ce* perpendicular to *cf*. Make *ce* equal to *cd*, and join *ea*; then will the angle *eaf* be the inclination of the curved surface of the cylindric intrados, and the face of the ring-stones.

We have now ascertained two sides, and the contained angle of the trehedral; in order to find the remaining parts, the third side of this trehedral is the angle of the joints of the intrados and face of the arch, by applying the proper curved moulds to the angular point; it is, however, rather unfavorable to our purpose, that the angle *abd*, *fig.* 4, is a right angle, and that the angles *lft* and *lfh*, *fig.* 3, differ but in a very small degree from right angles. As from this circumstance the principle cannot be made evident, we shall therefore suppose, that these angles have at least a certain degree of obliquity.

In *figs.* 6 and 5, let ABC equal to angle *lft* *fig.* 3, and ABD, *figs.* 6 and 7, equal to the angle *abd*, *fig.* 4: thus, in *figs.* 6 and 7, draw D*e*, intersecting AB in *f*, or producing D*e* to meet AB in *f*. At the point *f* in the straight line *ef* in *fig.* 7, make the angle *efg* equal to the angle *eac*, *fig.* 5; or in *fig.* 6, make the angle *efg* equal to the supplement of the angle *eaf*. In *figs.* 6 and 7, draw *ek* perpendicular to BC, BC in *i*, or BC produced in *i*. Draw *eg* perpendicular to *ef*, and *eh* to *e*C. Make *eh* equal to *eg*, and join *hi*. Make *i*K equal to *i*h, and join BK; then will the angle CBK be the angle of the joints of the intrados and face of the arch.

Fig. 1.

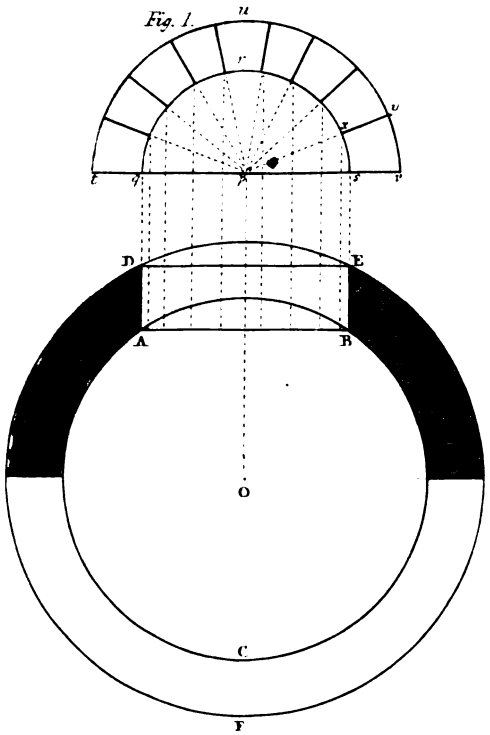
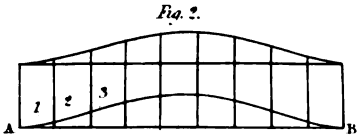


Fig. 2.



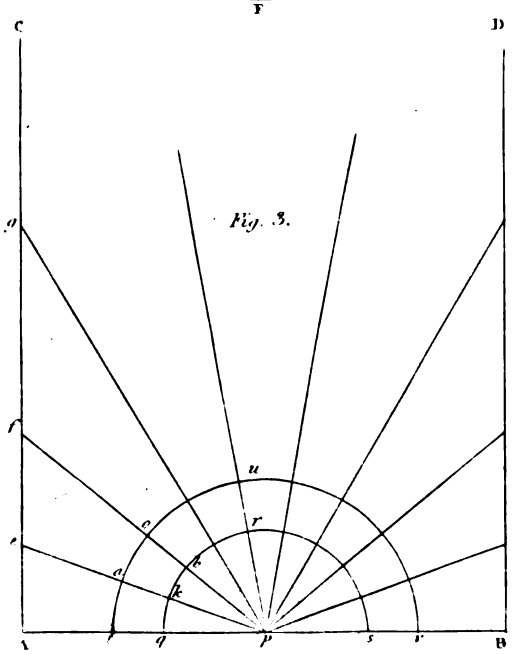
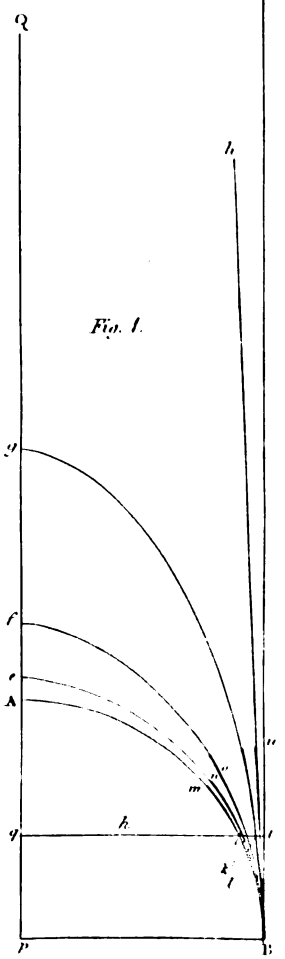


Fig. 3.

Fig. 4.



When each of the given sides is a right angle, then the remaining side of the trehedral will be the same as the contained angle; that is, the angle of the joints of the intrados and face of the arch, will be the same as the angle *eaf*, *fig.* 5. In this case, no lines are necessary in order to discover the angle of the joints.

In order to apply the angle CBK, one of the lines which applies to the face must be straight, and the curved edge shown by the bevel at D of the preceding plate must be so applied, that the other leg of the bevel may be a tangent to the curve at the angular point B, and this will complete what is necessary in the construction of an oblique arch with spiral joints.

SECTION VII.

A CIRCULAR ARCH IN A CIRCULAR WALL.

PROBLEM I.

To execute a semi-cylindric arch in a cylindric wall, supposing the axes of the two cylinders to intersect each other. Given the two diameters of the wall, and the diameter of the cylindric arch, and the number of arch-stones.

Fig. 1, *Plate* XVI. From any point *o* with the radius of the inner circle of the wall describe the circle ABC, or as much of it as may be necessary; and from the same point *o*, with the radius of the exterior face of the wall describe the circle DEF, or as much of it as may be found convenient.

Apply the chord AB equal to the width of the arch, and draw DA and EB perpendicular to AB or DE; then ABDE will be the plan of the cylindric arch.

Draw O*p* perpendicular to AB, and draw *tv* perpendicular to O*p*. From the point *p* as a centre, with the radius of the intrados of the arch describe the semi-circular arc, *qrs*; and from the same point *p*, with the radius of the extrados, describe the semi-circular arc *tuv*. Divide the arc *qrs* into as many equal parts as the arch-stones are intended to be in number, that is, here into nine equal parts. From the centre *p*, draw lines through the points of division to meet the curve *tuv*; and these lines will be the elevation of the joints; and the joints, together with the intradosal and extradosal arcs, will complete the elevation of the arch.

Find the developement, *fig.* 2, as in *fig.* 3, *Plate* VIII, and the parallel equi-distant lines to the same number as the joints in the elevation, will be the joints of the soffits of the stones; and the surfaces comprehended by the parallel lines, and the edges of the developements, will be the moulds for shaping the soffits of the stones.

In *fig.* 3. Let AB be equal to the diameter of the external cylinder. Draw AC and BD each perpendicular to AB. Bisect AB in *p*, from which describe the interdosal and extradosal arcs, and draw the joints as in *fig.* 1. Produce the joints to meet AC or BD, in the point *e*, *f*, *g*, &c.; then it is evident that since every section of a cylinder is an ellipse, the lines *p*A, *pe*, *pf*, *pg*, &c. are the semi-transverse axis of the curves, which form the joints in the face of the arch, and that these curves have a common semi-conjugate axis equal to half the diameter of the cylinder.

Therefore upon any indefinite straight line *pQ*, *fig.* 4, set off the semi-axis *pA*, *pe*, *pf*, *pg*, &c. and draw *pB* perpendicular to *pQ*. From *p*, with the radius *pA*, describe an arc AB. On the semi-axes *pe* and *pB*, describe the quadrantal curve of an ellipse; in the same manner describe the quadrantal curves *fB*, *gB*, &c. Make *pq* equal to *pq*, *fig.* 3, and in *fig.* 4 draw *qt* parallel to *pB*, intersect the curves AB, *eB*, *fB*, &c. in the points *i*, *k*, *l*, &c.; then *him*, *hkn*, *hle*, &c. are the bevels to be applied in forming the angles of the joints: viz. the bevel *him* is that of the impost, the straight side *hi* being applied upon the soffit or intrados; and the curved part *im* horizontally to the curve of the exterior side of the wall: the point *k*, of the bevil *hkn*, *fig.* 4, applies to the point *k*, *fig.* 3, so that *kh* may coincide with the joint upon the intrados, and the curved edge *kn*, *fig.* 4, upon the face *kn*, *fig.* 3; and so on.

As to the angles which the beds of the stones make with the intrados, they are all equal, and may be found from the elevation *svyx*, *fig.* 1; which is the same as a section of one of the arch-stones perpendicular to any one of the joints on the soffits.

The faces of the stones must be wrought by a straight edge, by perpendicular lines. The first thing to be done is to work one of the beds; secondly, work the intrados—at first as a plane surface at an angle *sxy*, or *xsv*, *fig.* 1; then gauge off the bed of the soffit, and work the other bed of the stone by the angle *vsx* or *yxs*; then apply the proper soffit, 1, 2, or 3, *fig.* 2; and lastly, the two moulds in *fig.* 4.

SECTION VIII.

A CONIC ARCH IN A CYLINDRIC WALL.

PROBLEM I.

To execute a semi-conic arch in a cylindric wall, supposing the vertex of the cone to meet the axis of the cylinder. Given the interior and exterior diameters of the wall, the length of the axis of the cone, and the diameter of its base.

EXAMPLE I.

From the point *o*, *fig.* 1. *Plate* XVII, with the radius of the interior surface of the wall describe the arc ABC, and from the same point O with the radius of the exterior surface, describe the arc DEF, and the area between the arcs ABC and DEF will contain the plan of the wall.

Draw any line O*p*, and make O*p* equal to the length of the axis of the cone. Through *p* draw *tv* perpendicular to O*p*. From *p* as a centre, with the radius of the base of the cone, describe the semi-circle *qrs* meeting *tv* in the points *q* and *s*. Divide the arc *qrs* into as many equal parts as the arch-stones are to be in number, that is, in this example, into nine equal parts. Through the points of division draw the joint lines, which will of course radiate from the centre *p*. The extradosal line *tuv* is here described, as we here suppose the cone to be of an equal thickness, and consequently the axis of the exterior cone longer than that of the interior.

Fig. 1.

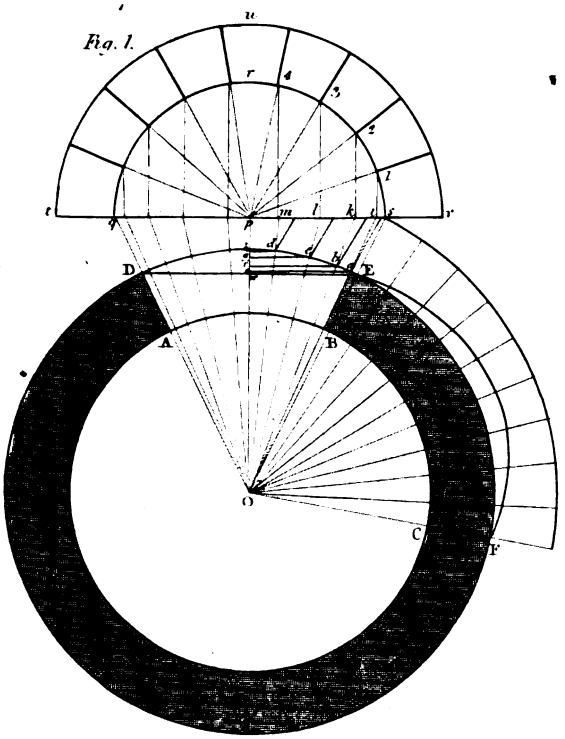


Fig. 2.

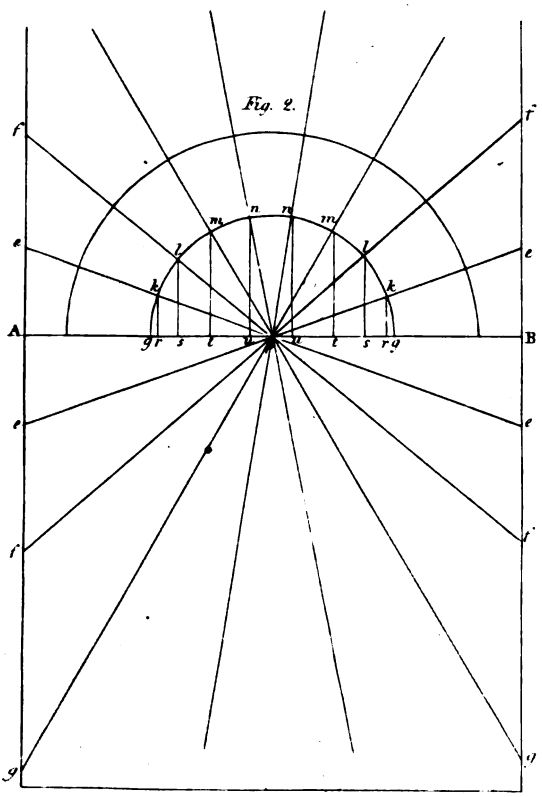


Fig. 3.

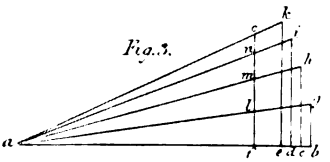


Fig. 5.

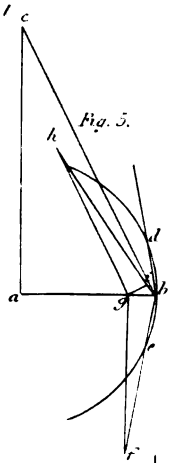
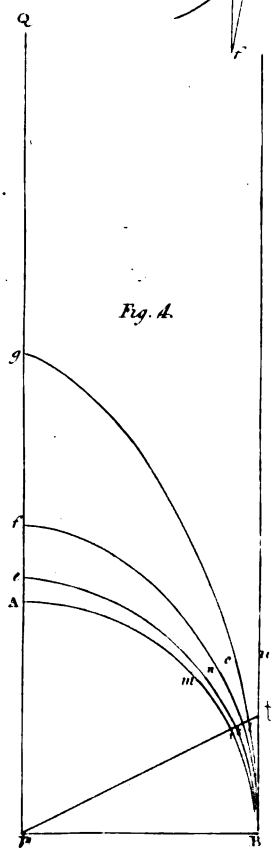
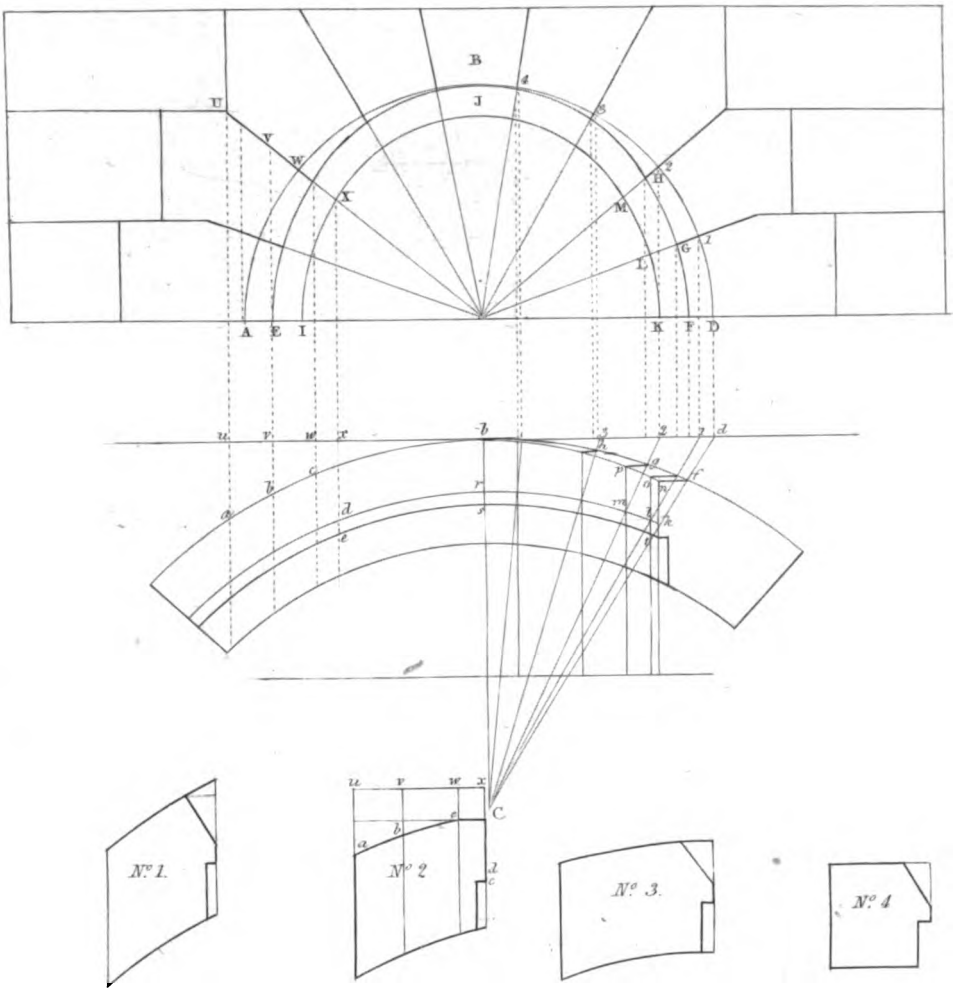


Fig. 4.





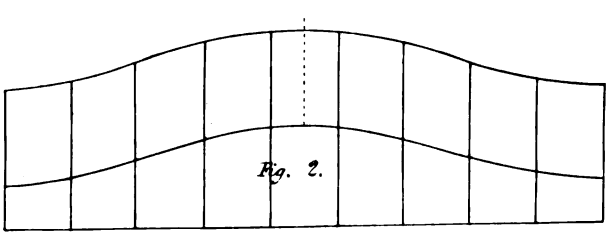


Fig. 2.

From the points 1, 2, 3, &c. where the lower ends of the joints of the arch stones meet the intradosal arc, draw lines perpendicular to *tv*, meeting *tv* in the points *i*, *k*, *l*, *m*, &c. From these points draw lines to the vertex of the cone at *o*, meeting the arc DE or plan of the wall under the arch, in the points *a*, *b*, *c*, *d*, &c. Draw the lines *ae*, *bf*, *cg*, *dh*, &c., parallel to the chord DE, to meet *op* in *w*. In *fig.* 2, draw the straight line AB, in which take the point *p* near the middle of it, and make *p*A, *p*B, each equal to the radius of the exterior surface of the cylindric wall. Through the points A and B draw *fg*, *fg*, perpendicular to AB.

From the point *p* as a centre, with any radius, describe a semi-circular arc, and divide it into nine equal parts as before. Through the points of division draw the radiating lines to meet *fg* in the points *e*, *f*, *g*, &c. From *fig.* 1 transfer the distanecs E*w*, *ae*, *bf*, *cg*, &c. *fig.* 1 to *pg*, *fig.* 2 *pr*, *ps*, *pt*, &c. on each side of the point *p*. Draw the perpendiculars *rk*, *sl*, *tm*, &c. to AB, which will intersect with the radials *pe*, *pf*, *pg*, &c. in the points *k*, *l*, *m*, &c.; through the points *k*, *l*, *m*, &c. on each side draw a curve, and this curve will be the elevation of the intrados of the arch.

Fig. 3 exhibits another method by which the heights of the points *k*, *l*, *m*, *fig.* 2 might have been found. This method is as follows:—Upon a straight line *ab*, and from the point *a* make *ab'*, *ac*, *ad*, *ae*, &c. and *af* respectively equal to *oi*, *ok*, *ol*, &c. *fig.* 1. In *fig.* 3, draw the straight lines *bg*, *ch*, *di*, *ek*, *fo*, perpendicular to *ab*. Make *bg*, *ch*, *di*, *ek*, respectively equal to the heights *i*1, *k*2, *l*3, *m*4. Draw the straight lines *ag*, *ah*, *ai*, *ak*, intersecting *fo* in the points *l*, *m*, *n*, *o*.

In *fig.* 2, make *rk*, *sl*, *tm*, *un*, respectively equal to *fl*, *fm*, *fn*, *fo*, *fig.* 2, and thus the points *k*, *l*, *m*, &c. are found by a different method, which is more accurate for ascertaining the points near the top, as the radials and the perpendiculars intersect more and more obliquely as they approach the summit.

In some line *p*Q, *fig.* 4, make *p*A, *pe*, *pf*, *pg*, &c. equal to *p*A, *pe*, *pf*, *pg*, &c. *fig.* 2. Draw *p*B perpendicular to *p*Q. From *p* with the radius *p*A, describe the arc AB. With the several semi-axes *pe*, *p*B; *pf*, *p*B; *pg*, *p*B, &c. describe the quadrantal elliptic curves *en*B, *fo*B, &c. Draw B*u* parallel to AQ. Make the angle B*pt* equal to the angle P, *o*E, *fig.* 1; and let *i*, *k*, *l*, &c. be the points where *pt* intersects the curves AB, *e*B, *f*B, &c. Then the bevels of the joints are *him*, *hkn*, *hlo*, &c.

Now, if EBCF, *fig.* 1, be the developement of the intrados, with the joints drawn on it, we shall have the soffits of the stones.

In *fig.* 5, draw *ab* and *ac* at a right angle with each other. Make *ab* equal to the radius of the base of the cone, and *ac* equal to the length of its axis. Join *bc*. From *a*, with the radius *ab*, describe an arc, *dbe*. Make *be* equal to the chord of the intrados of one of the arch-stones. Produce *be* to any point *f*, and draw *fg* perpendicular to *ab*, meeting *ab* in *g*. Draw *gi* perpendicular to *bc*, and *gh* parallel to *bc*. Make *gh* equal to *gf*, and join *hi*; then *hig* is the angle which the soffits of the stones, when wrought as planes, make with the beds.

EXAMPLE II.

To construct an arch in a cylindric wall, of which arch the intrados is a uniform conic surface, so that the axes of conic and cylindric surfaces may meet or intersect each other.

In *fig.* 1, *Plate* XVIII, which is the plan and elevation of the arch, the elevation being above, and the plan below, as usual, let AD be considered as the ground-line, and ABD the elevation of the base of the cone, which base is supposed to be a tangent plane to the surface of the wall; let *bd*, parallel to the ground-line AD, be the half plan of the base of the cone; *a'b'c'hgf* the plan of the cylindric face of the wall; and *d'rmlk* the plan of the intersections of the conic and the intermediate cylindric surfaces which terminate the interior of the aperture of the arch.

First, to find the elevation of the intersections of the cylindric face of the wall and the conic surface of the intrados. Having divided the semi-circular arc DBA, into the equal parts D1′, 1′2′, 2′3′, &c. at the points 1′, 2′, 3′, &c., draw the connecting lines D*d*, 1 1, 2′2, 3′3, &c. meeting *bd* in the points *d*, 1, 2, 3, &c. Draw *bc* perpendicular to *bd*, and make *bc* equal to the axis of the conic surface.

Draw the straight lines *dc*, 1*c*, 2*c*, &c. meeting the plan of the face of the wall in the points *f*, *g*, *h*, and draw the connecting lines *f*F, *g*G, *h*H, &c. intersecting the lines FC, GC, HC, &c. in the points F, G, H, &c. A sufficient number of points being found in the same manner, through these points draw the curve EBF, and the curve EBF will be the elevation of the line of intersection of the conic and cylindrical surfaces required.

To find the elevation of the intersection of the conic surface with the intermediate concentric cylindric surface. Let the arc *d'rk* be the plan of this concentric cylindric surface, having the same centre as the arc *a' b' f*, which is the plan of the cylindric surface of the wall; and let the straight lines *dc*, 1*c*, 2*c*, &c. meet the arc *drk* in the points *k*, *l*, *m*, &c.; then, if connectants be drawn from the points *k*, *l*, *m*, to the elevation to meet the radial lines, we shall thus obtain the elevations K, L, M, of the corresponding points. Let us now suppose that a sufficient number of points are thus found, and the curve IJK drawn through these points; then IJK will be the elevation of the intersection of the conic and cylindric surfaces required.

Let us now construct a mould for one of the joints, suppose for the second joint UX, in the elevation. Draw the connectants U*u*, V*v*, W*w*, X*x*, meeting the line *db* prolonged in the points *u*, *v*, *w*, *x*′, and prolong the connectants U*u*, V*v*, W*w*, &c. to meet the plan of the exterior cylindric surface of the wall, in the points *a*′, *b*′, *c*′,; and the connectant X*x* to meet the plan of the intermediate cylindric surface in the point *d*′, and the plan *est* of the inner cylindric surface on the point *e*.

Suppose No. 1, No. 2, No. 3, No. 4, to be the figures of the moulds of the first, second, third, and fourth joints from the springing-line; and as it is proposed to find the figure of the joint, No. 2, draw the straight line *ux*, No. 2, and in *ux* take *uv*, *vw*, *wx*, respectively equal to UV, VW, WX, in the elevation *fig.* 1. Draw in No. 2, *ua*, *vb*, *wc*, *xe*, perpendicular to *ux*, and make *ua*, *vb*, *wc*, *xd*, *xe*, respectively equal to *ua*′, *vb*′, *wc*′, *xd*′, *xe*′, on the plan *fig.* 1. Through the points *a*, *b*, *c*, No. 2, draw a portion of an ellipse, and we shall have the edge of the joint that meets the surface of the wall. Draw the straight line *cd*, No. 2, and this straight line will be the intersection of the joint and the conic surface; the portion *de*, No. 2, will be the section of the inner cylindric surface.

The remaining lines of the figure of the mould will be found in the same manner, and thus we shall have the complete figure, No. 2, of the mould.

Fig. 2 exhibits the developement of the soffit of the horizontal cylindritic surface next to the aperture, upon the supposition that the face of the ring-stones are first wrought in horizontal lines from the curve EBF, to meet the inner horizontal cylindritic surface, and afterwards reduced to the conic form. The breadth of the stones in this developement are not equal, but increase from each extreme to the middle.

The mould for the springing-stone is the same as the plan of the jamb.

It will be necessary to work the arch-stones into prisms, of which the ends are the sections of the stones in the right section of the arch, viz. the same as the compartments adjacent to the curve in the elevation. The prisms being formed, draw the figure of the soffit of the stone upon the surface intended for the same. Then apply the joint-mould upon each face of the stone intended for the joint, and draw the figure of the joints; then reduce the end of the stone which is to form a part of the face of the arch in such a manner that when the arch-stone is placed in the position which it is to occupy, or in a similar situation, a straight edge, applied in a horizontal position, may have all its points in contact with the surface of the face of the stone now formed. The face being thus formed, the conic surface must also be formed by means of a straight edge, in such a manner that all points of the straight edge must coincide with the surface when the straight edge is directed to the centre of the cone.

SECTION IX.

CONSTRUCTION OF THE MOULDS FOR SPHERICAL NICHES, BOTH WITH RADIATING AND HORIZONTAL JOINTS, IN STRAIGHT WALLS.

When niches are small, the spherical heads are generally constructed with radiating joints meeting in a straight line, which passes through the centre of the sphere perpendicularly to the surface of the wall, when the wall is straight; but when it is erected upon a circular plan, the line of common intersection of all the planes of the joints is a horizontal line tending to the axis of the cylindric wall.

Niches of large dimensions will be more conveniently constructed in horizontal courses, than with joints which meet in the centre of the spheric head; since in the latter, the length and breadth of the stones are always proportional to the diameter or radius of the sphere, and therefore when the diameter is great, the stones would be difficult to procure.

The construction of niches depend also upon the nature and position of the surface from which they are recessed; viz. a spherical niche may be made in a straight wall, either vertical or inclined; or it may be constructed in a circular wall, or a spherical surface, such as a dome.

This subject, therefore, naturally divides itself under several heads or branches; the principal are, a spherical niche in a straight wall, with radiating joints; a spherical niche in a straight wall, in horizontal courses; a spherical niche in a circular wall, with radiating joints; a spherical niche in a circular wall, in horizontal courses; and, a spherical niche in a spherical surface or dome.

SECTION X.

EXAMPLES OF NICHES, WITH RADIATING JOINTS, IN STRAIGHT WALLS, AS IN PLATE XIX, *Fig.* 1.

NICHES of very small dimensions will be easily constructed in two equal cubical stones, hollowed out to the spherical surface, with one vertical joint; the portion of the spherical surface, formed by both stones, being one fourth of the entire surface of the sphere.

Fig. 2 is the elevation, *fig.* 3 the plan, and *fig.* 4 the vertical section perpendicular to the face of the straight wall of such a niche.

The first operation is to square the stone; viz. to bring the head of each stone to a plane surface, then the vertical joints and the upper and lower beds to plane surfaces at right angles with the surface which forms the head.

The two stones as hollowed out are shown at Nos. 3 and 4. To show how they are wrought, we will commence with one of the stones after being brought to the cubical form. Let this stone be No. 3. In the solid angle of the stone formed by the head, the vertical joint and the lower bed meeting in the point *p*, apply the quadrantal mould, No. 2, upon each side, so that the angular point of the two radiants may coincide with the point *p*, and one of the radiants upon the arris of the stone which joins the point *p*; then if the face of the quadrantal mould coincide with the surface of the stone, the other radiant line will also coincide, because the angle of the mould, and all the angles of the faces of the stone, are right angles.

By this means we obtain by drawing round the curved edge of the mould, the three quadrantal arcs *abc*, *agh*, and *cih*. The superfluous stone being cut away, the spherical surface will be formed by trial of the mould, No. 2.

Fig. 1, *plate* 20, is the elevation, and *fig.* 2, the plan of a niche in a straight wall.

The elevation, *fig.* 1, not only shows the number of stones which must be odd, and the number of radiating joints which must in consequence be one less than the number of stones, but also the thickness of these stones, and the moulds for forming the heads and opposite sides.

The head of the niche being spherical, makes it a surface of revolution. It follows therefore, that the sections through the joints are equal and similar figures; hence, if all the joints were of one length, one mould would be sufficient for the whole; but since, in this example, they are of different lengths, every two joint moulds will have a common part; and thus if the mould for the

Fig. 2.

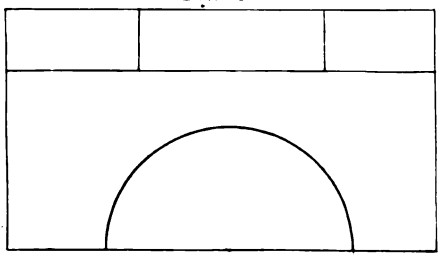


Fig. 1.

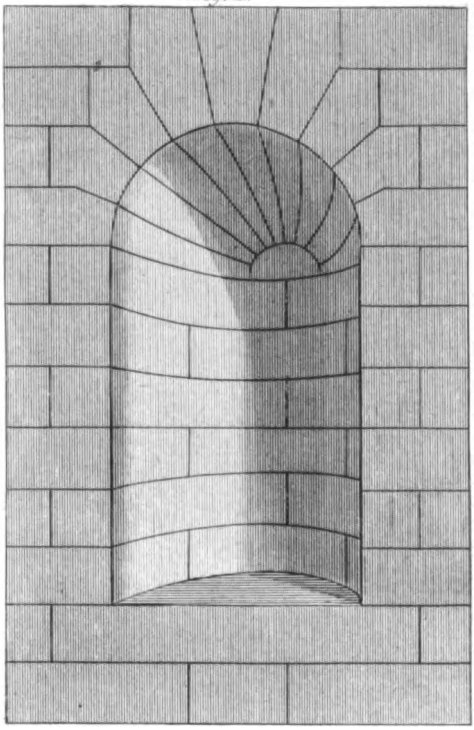


Fig. 3.

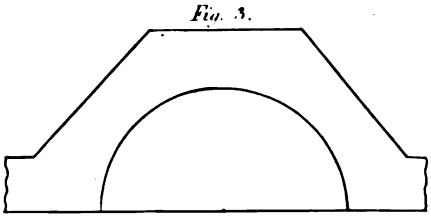
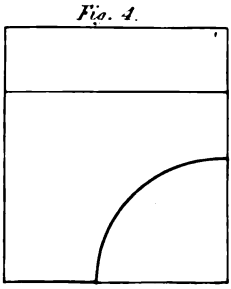
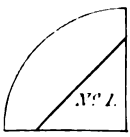
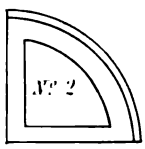
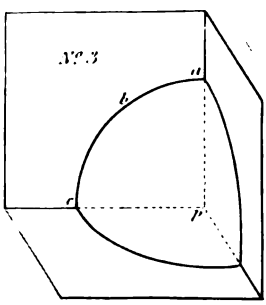


Fig. 4.









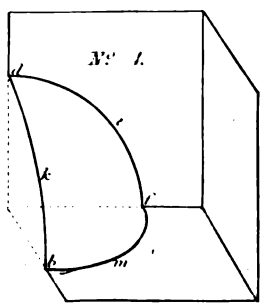
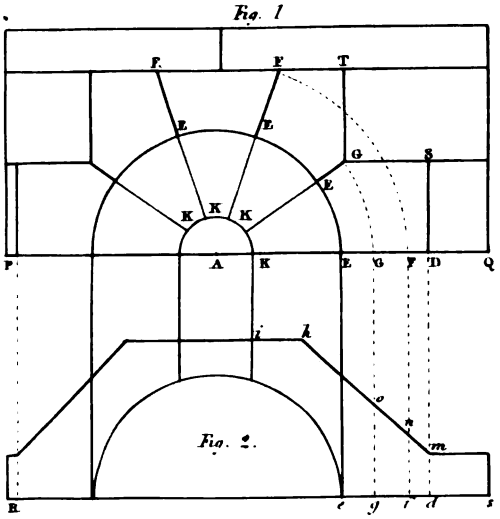


Fig. 1



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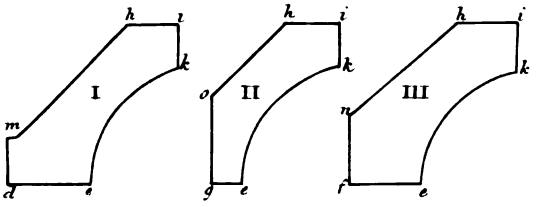

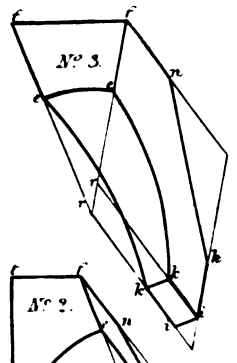

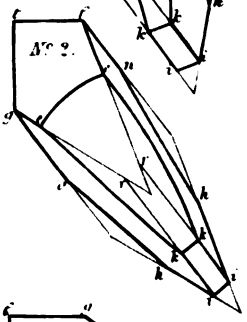

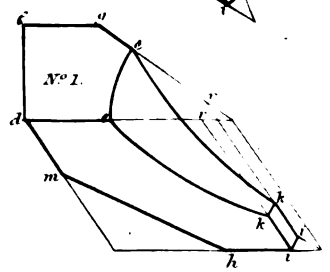

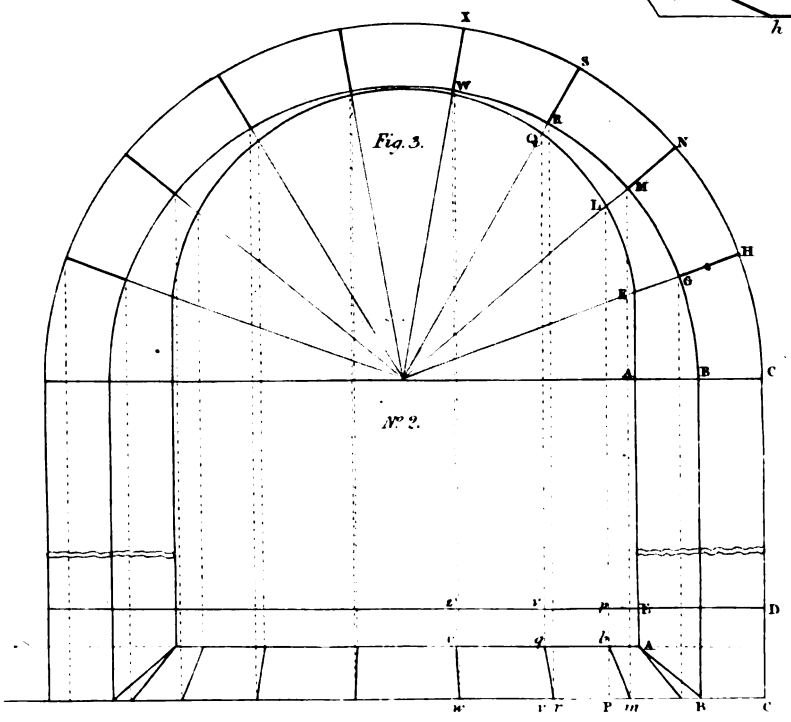

Fig. 3.

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longest joint be found, each of the other moulds will only be a part of the mould thus found.

In order to ascertain the mould for each joint, the longest being AD, *fig.* 1, extending from the centre to the extremity of the stone upon one side of the plan, the next longest is AF, extending from the centre to the extremity of the keystone, and the shortest AG.

Upon PQ, *fig.* 1, make AF equal to AF″, and AG equal to AG′. Perpendicular to PQ drawn D*d*, F*f*, G*g*, meeting the front line RS of the plan, *fig.* 2, in the points *d*, *f*, *g*, intersecting the back line of the stone in the points *m*, *n*, *o*: then will No. 1, *kikedm* be the mould for the first stone raised upon the plan, *kikefn* the mould for the joint on each side of the keystone, *hikego* the mould for the first stone above the springing line. These moulds are shown separately at I, II, III, and identified by similar letters.

Nos. 1, 2, 3, exhibit the first, second, and third stones of the niche as if wrought to the form of the spherical surface; No. 3 being the keystone; therefore the two remaining stones are wrought in a reverse order to the stones exhibited at No. 1 and No. II.

The first part of the operation is to work the stones into a wedge-like form, so that the right section of these stones may correspond to the figures formed by the radiations of the joints to the centre A, *fig.* 1, and by the horizontal and vertical joints of the stones adjacent to those which form the niche; for this purpose, two moulds for each head will be necessary, viz. one whole mould must be made for each stone, and one mould for the part within the circle, which will apply to every stone, in order to form the extent of the part within the recess: thus a mould formed to the sectoral frustrum EE′K′K in the elevation, *fig.* 1, will apply alike to all stones, as will be shown presently.

The next thing is to form the moulds K′KDSG′, K″K′G′TF″ and K″K′F″F″ of the heads; the application of these moulds is as follows:—

Having wrought the under bed, the head and back of each stone, and having formed a draught next to the edge of the bed, upon the side which is to lie upon the cylindric part in the centre, at a right angle with the head, apply the mould K′KDSG′, *fig.* 1, upon the head of the stone, No. 1, so that the straight edge KD may be close upon the bed of the stone, and draw by the other edges of the mould; thus applied the figure *r′rdsg*; and, in the same line *rd*, close to the bed, apply the mould K′KE′E′, *fig.* 1, and by the other edges of this mould draw the figure *r′ree′*. Apply the mould K′KDSG′, to the opposite or parallel side of the stone, close to the bed, and draw a similar and equal figure as was done by the same mould when it was applied to the head; this done, work the upper bed of the stone.

Proceed in like manner with the stones exhibited at No. 2 and No. 3, and similarly with the stones on the left-hand side of the arch; the stones No. 1 and No. 2 answering to those on the right hand of the keystone.

In order to show the application of the moulds marked I. II. III. at the bottom of the plate, taken from the plan, *fig.* 2; the mould I. applies to the under bed of the stone, No. 1; the next mould II. applies upon the upper bed of No. 1, and upon the under bed of No. 2; and the mould III. applies upon the upper bed of No. 2, and upon each side of the keystone, No. 3.

As every arch has both a right and left hand side, and as every joint is formed by the surfaces of two stones, every mould has four applications, one on each of the four stones.

In order to render these applications of the moulds I. II. III. as clear as possible, the corresponding situations of the points marked upon each stone by each respective mould, are marked by similar letters to those on the moulds I. II. III. or their correspondents on the plan, fig. 2, viz. on the under bed of the stone, No. 1, will be found the letters *h*, *i*, *k*, *e*, *d*, *m*, as in the mould I.; upon the under bed of No. 2, will be found *h'*, *i'*, *k'*, *e'*, *g'*, *o'*; as also upon the upper bed, of No. 1, *i'*, *k'*, *e'*, *g'*, and upon the right hand side of the keystone, No. 3, will be found the letters *h''*, *i''*, *k''*, *e''*, *f''*, *n''*, as also similar letters upon the upper bed, No. 2, to those of the mould III.

ARCH, WITH SPLAYED JAMBS.

To find the angles of the joints formed by the front and intrados of an elliptical arch, erected on splayed jambs.

No. 1, on fig. 3, is the place of the impost; No. 2, the elevation.

The impost A'B'C'D'E is the first bed; *f g h i k*, the second; *l m n o p*, the third; *q r s t u*, the fourth; *v w x y z*, the fifth. The other beds are the same in reverse order. The breadth of all these beds is the same as that of the arch itself. The lengths *k*K, *n*P, *s*U, *x*Z, of the front lines of the moulds of the beds are respectively equal to the lines HF, NL, SQ, X*V*, on the face of the arch. And also, *hg*, *nm*, *sr*, *xw*, on the parts of the moulds equal to the corresponding distances HC, NM, SK, XW, on the face of the arch. The distances *kf*, *pl*, *ug*, *rv*, are equal to the perpendicular part AE of the impost.

SECTION XI.

EXAMPLES OF NICHES IN STRAIGHT WALLS WITH HORIZONTAL COURSES, AS IN PLATE XXI, *Fig.* 1.

Let *fig.* 2 represent a niche with horizontal courses, No. 1 being the elevation, exhibiting three arch-stones on each side of the keystone, and No. 2 the plan, consisting of two stones, making together a semicircle, each being one quadrant.

The heads of the stones in the wall, on the right-hand side of the arch, which also form a portion of the concave surface, are ABCDE, FDCGHM, MGKLM, and the key-stone LKKL. Round each of these figures circumscribe a rectangle, so that two sides may be parallel and two perpendicular to the horizon: thus round the head of the stone ABCDE circumscribe the rectangle ANOE' round the figure FDCGMI, the head of the second stone, circumscribe the rectangle PQRI, &c.

Draw the straight lines *am*, and *ai*, *fig.* 3, No. 1, forming a right angle with each other; from the point *a* as a centre, with the radius *d b c* describe the arc *cc'*, meeting the lines *am* and *ai* in the points *c*,*c'*.

Fig. 1.

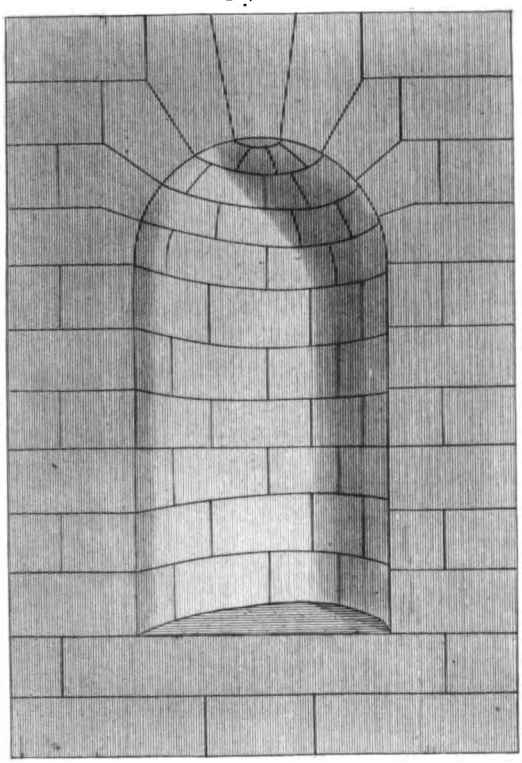


Fig. 7.

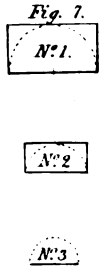


Fig. 5.

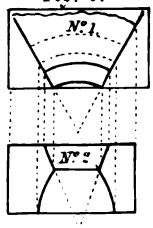


Fig. 6

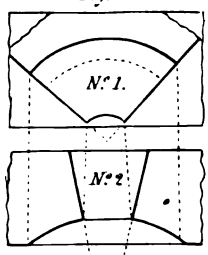


Fig. 3

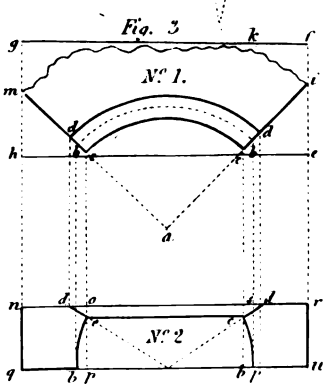


Fig. 2.

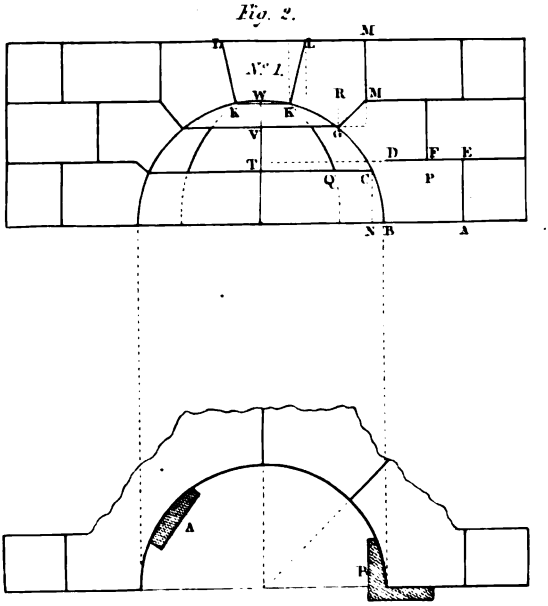


Fig. 4.

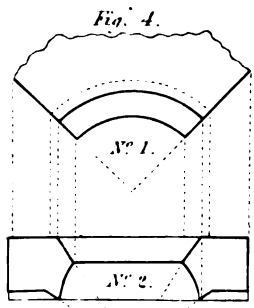


Fig. 1.

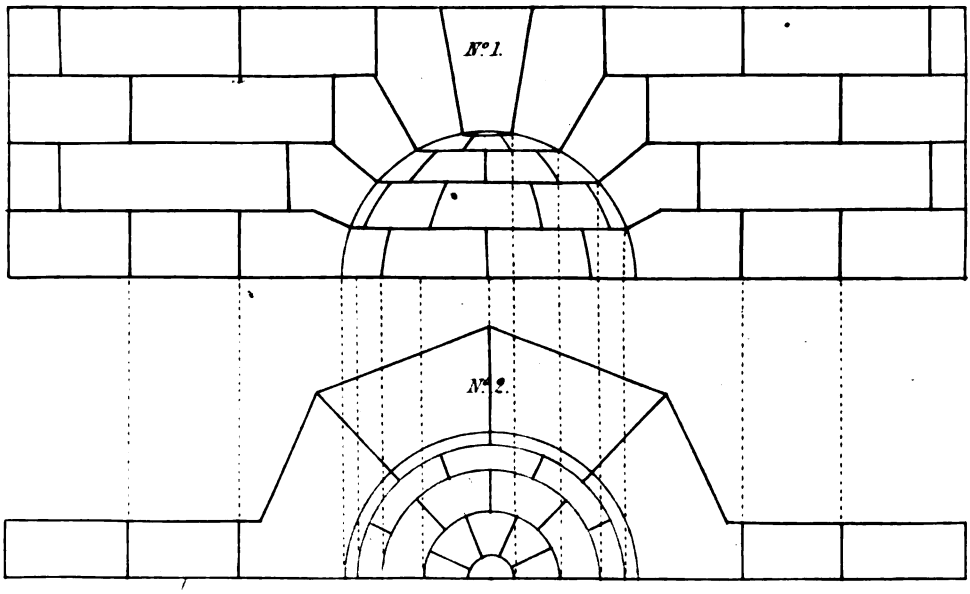
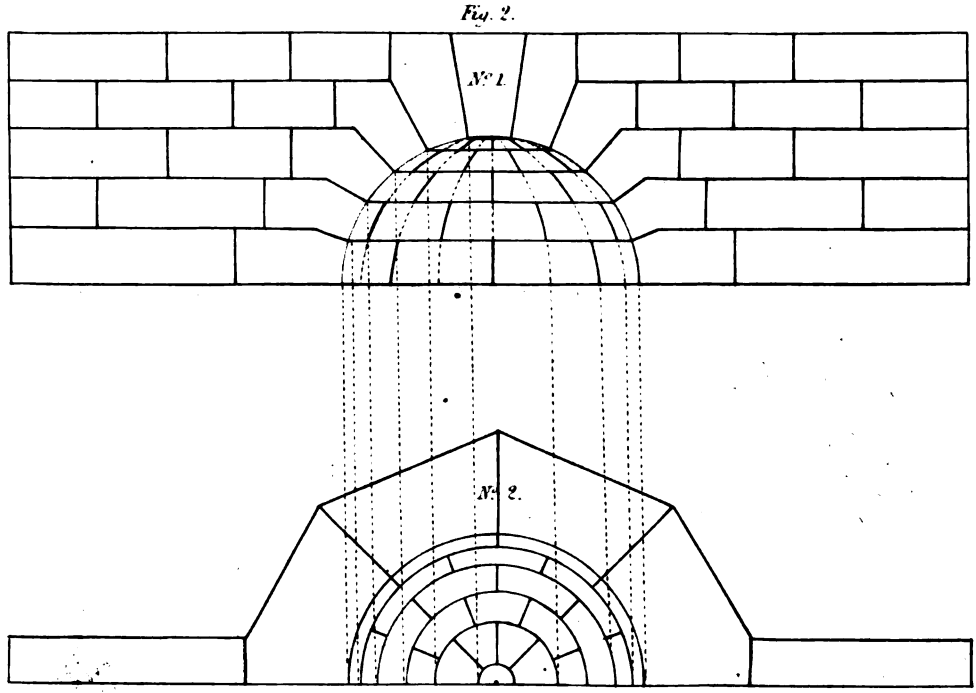


Fig. 2.



Let the quadrangular figure *hgfe*, No. 1, be considered as the upper bed of a stone, which, as well as the lower bed, is wrought smooth, these two surfaces being parallel planes at a distance from each other equal to the line AE or CD, *fig.* 2. Moreover, let *mcc'bb, dd* be considered as a mould made to the figure before described and laid flat on the upper bed of the stone in its true position, the points *c,c'* of the mould being brought as near to the side *he* as will just leave a sufficient quantity of stone, in order to work it complete. By the edges of the mould thus placed draw the curve *cc'*, the straight lines *cm* and *c'i*, and the rough edges *ik* and *ml*.

Perpendicular to the upper bed, and along the arc *cc'*, cut the stone so as to form a surface perpendicular to the upper bed, and the surface thus formed will necessarily be cylindric; through each of the straight lines *cm* and *c'i* cut a surface perpendicular to the said upper bed, and these surfaces will be the planes of the vertical joints, and will be at a right angle with each other; then with a guage, of which the head is made to the cylindric surface, and which is set to the distance OD, *fig.* 2, No. 1, draw the curve line *dd* on the upper bed of the stone. Upon the lower bed of the stone, with the guage set to the distance NB, draw the arc *bb'*.

The thickness of the stone is exhibited at No. 2, *fig.* 3, the upper bed being represented by the line *nr*, and the lower bed by the line *qu*, so that *nr* and *qu* are parallel lines, the distance between them being equal to the thickness of the stone, *viz.* equal to AE, *fig.* 2, No. 1. Lastly, with a plane or common guage set to the distance NC, *fig.* 2, No. 1, draw the line *cc* on the cylindric surface, *fig.* 3, No. 1.

Now, in *fig.* 3, the line *dd'*, No. 2, represents the arc *dd'*, No. 1; *cc'*, No. 2, represents the arc *cc'*, No. 1; and *bb'*, No. 2, represents the arc *bb*, No. 1: so that the stone must be cut away between the line *dd'* on the upper bed, and *cc'* on the cylindric surface, by means of a straight edge, so as to form a conic surface; this may be done by setting a bevel to the angle EDC, *fig.* 2, No. 1. The conic surface thus formed will be one side of the joint within the spheric surface.

Again, cut away the stone between the line *cc'* on the cylindric surface, and the arc *bb'* before drawn on the lower bed by means of the curved bevel shown at A, *fig.* 2, No. 2, so as to form a spherical surface. This may be done in the most complete manner, by applying the straight side of the curved bevel B, *fig.* 2, No. 2, to the under bed of the stone, so as to be perpendicular to the curve; then, if the curved edge coincide at all points, the surface between these lines will be spherical, and will form that portion of the head of the niche which is contained on the stone.

In the same manner all the other stones may be cut to the form required.

Fig. 4 exhibits the stone in the middle of the second course, and *fig.* 5 the stone on the left of the same course in the angle, which last stone is one half of the stone represented by *fig.* 4.

Fig. 6 exhibits the left-hand stone of the third course, and *fig.* 7 the keystone, which is wrought into the frustrum of a cone to a given height, in order to agree with the circular courses; and to prevent any tendency of the keystone from coming out of its place, the upper part is cut into the frustrum of a pyramid.

Plate XXII, *fig.* 1, represents a spheric headed niche in a straight wall with four arch-stones on each side of the keystone, and therefore, also, with four horizontal courses; and as the joints are broken, if we begin the first course with four whole stones, as exhibited on the plan, No. 2, the next course will consist of three whole stones and two half stones in one in each angle. As the stones are here in this example projected on the plan as well as on the elevation, the elevation, No. 1, not only exhibits the number of courses, but the number of stones also in each course.

Fig. 2, represents a spheric headed niche in four courses besides the keystone. No. 2, the ground plan of No. 1.

It may be observed once for all, that the greater the dimensions of a niche, the greater must also be the number of courses in the height.

The principles for cutting the stones of these niches, is the same as has already been explained for Plate XXI.

SECTION XII.

CONSTRUCTION OF THE MOULDS, AND FORMATION OF THE STONES, FOR DOMES UPON CIRCULAR PLANES, AS IN PLATE XXIII, *Fig.* 1 & 2.

ON THE CONSTRUCTION OF SPHERICAL DOMES.

Since walls and vaults are generally built in horizontal courses, the sides of the coursing joints in spherical domes are the surfaces of right cones, having one common vortex in the centre of the spheric surface, and one common axis; hence the conic surfaces will terminate upon the spheric surface in horizontal circles: again, because the joints between any two stones of any course are in vertical planes passing through the centre of the spheric surface, the planes passing through all the joints between every two stones of every course will intersect each other in one common vertical straight line passing through the centre of the spheric surface.

The line in which all the planes which pass through the vertical joints intersect, is called the axis of the dome.

Because a straight line drawn through the centre of a spheric surface, perpendicular to any plane cutting the spheric surface, will intersect the cutting plane in the centre of the circle of which the circumference is the common section of the plane and spheric surface, the axis of the dome will intersect all the circles parallel to the horizon in their centre.

The circumference of the horizontal circle, which passes through the centre of the spheric surface, is called *the equatorial circumference*, and any portion of this circumference is called an *equatorial arc*.

The circumferences of circles, which are parallel to the equatorial circle, are called *parallels of altitude*, and any portions of these circumferences are called *arcs of the parallels of altitude*.

Fig. 1.

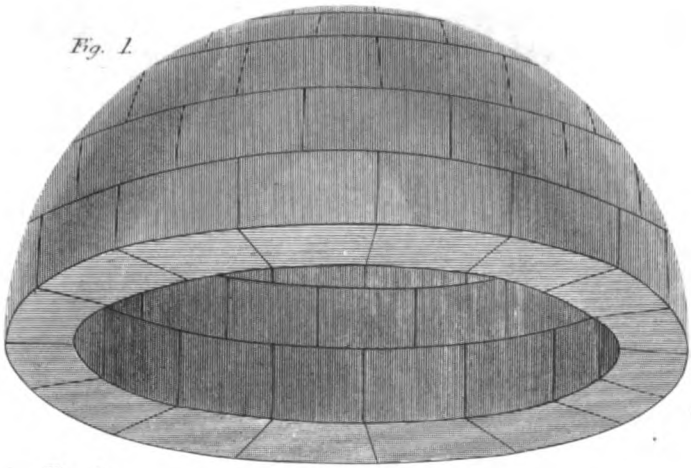


Fig. 2.

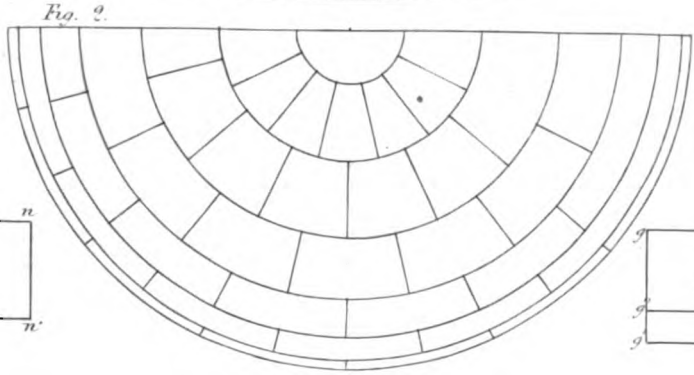


Fig. 6.

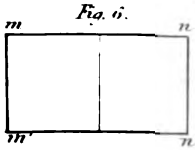


Fig. 8.

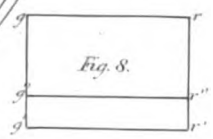


Fig. 9.

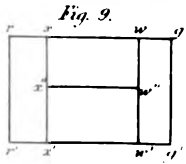


Fig. 7.

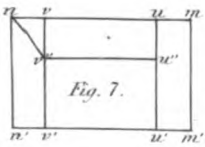
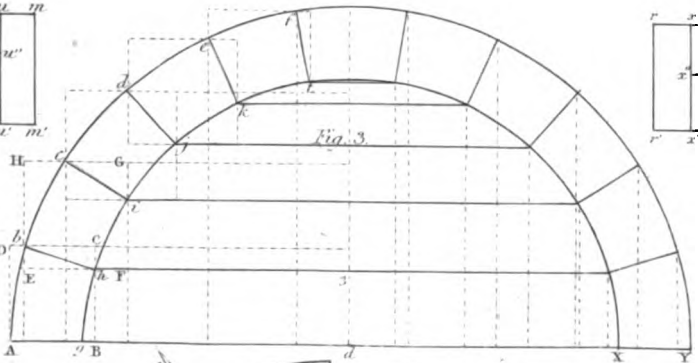


Fig. 3.



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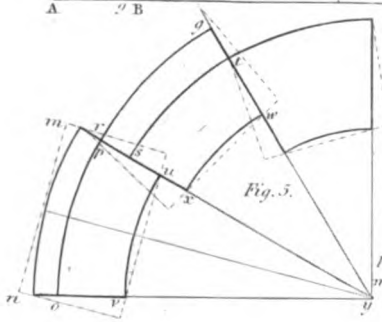
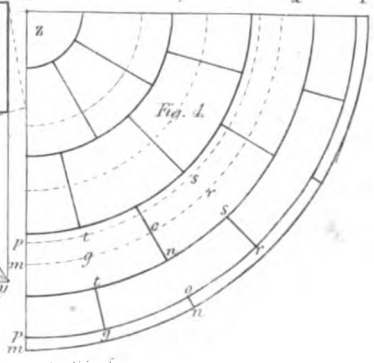


Fig. 4.



The intersection of the axis, and the spheric surface, is called *the pole of the dome.*

The arcs between the pole and the base of the dome, of the circles formed on the spheric surface by the planes which pass along the axis, are called *meridians*, and any portions of these meridians are called *meridional arcs.*

The conical surfaces of the coursing-joints terminate upon the spheric surface of the dome in the parallels of altitude, and the surfaces of the vertical joints terminate in the meridional arcs.

Hence in domes, where the extrados and intrados are concentric spheric surfaces, to apparent sides of each stone contained by two meridional arcs, and the arcs of two parallel circles are spheric rectangles, the two sides which form the vertical joints are equal and similar frustrums of circular sectors, and the other two sides forming the beds are frustrums of sectors of conic surfaces.

In the execution of domes, since the courses are placed upon conical beds which terminate upon the curved surfaces in the circumferences of horizontal circles, they are comprised between horizontal planes, and therefore may be said to be horizontal. Hence the general principle of forming the stones of a niche constructed in horizontal courses may likewise be applied in the construction of domes.

Each of the stones of a course is first formed into six such faces as will be most convenient for drawing the lines, which form the arrises between the real faces. Two of these preparatory faces are formed into uniform concentric cylindric surfaces, passing through the most extreme points of the axal section of the course in which the stone is intended to be placed, the axis of the dome being the common axis of the two cylindric surfaces of every course.

Two of the other surfaces are so formed as to be in planes perpendicular to the axis of the dome, and to pass through the most extreme points of the axal or right sections of the course, as was the case with the two cylindric surfaces.

The extreme distance of the two remaining surfaces depends upon the number of stones in the course. These surfaces are in planes passing through the axis, and are therefore perpendicular to the other two planes. As these planes, which pass through the axis, from the vertical joints, they remain permanent, and undergo no alteration except in the boundary, which is reduced to the figure of the axal section of the course.

In order to find the terminating lines of the last and permanent faces, draw the figure of the section of the course upon one of the two vertical joints in its proper position, then two of the corners of the mould will be in the two cylindric surfaces, one point in the one, and the other in the other, and the two remaining corners of the mould will be in the two surfaces which are perpendicular to the axis, one point of the mould being in the one plane surface, and the other point in the other plane surface.

Draw a line on each of the cylindric surfaces through the point where the axal section meets the surface parallel to one of the circular edges, and the line thus drawn on each of the cylindric surfaces will be the arc of a circle in a plane perpendicular to the axis of the two cylindric surfaces, and will be equal and similar to each of the edges of the cylindric surface to which it is parallel; but in the first course of a hemispheric dome, there will be no intermediate line on the convex side, since the circular arc terminating the lower edge, will also be the arris line of the convex spheric surface and the lower bed of the stone, which, in this course, is a plane surface.

In all the intermediate courses of the dome between the summit and the first course, the line drawn on the convex cylindric surface will be the arris line between the convex spheric surface, and the convex conic surface which forms the lower bed of the stone; and in all the courses from the base to the summit, the line drawn on the concave cylindric surface will be the arris line between the concave conic surface forming the upper bed, and the concave spheric surface of the stone, which concave surface will form a portion of the interior surface of the dome.

On the upper plane surface of each stone to be wrought for the first course, draw a line parallel to one of the circular edges; but in each of the stones for the intermediate courses between the first course and the key-stone at the summit, draw a line on each of the planes which are perpendicular to the axis parallel to either of the edges of the face upon which the line is made through the common point in the vertical plane of the joint and the horizontal plane, then the line drawn on the top of every stone will be the arris line between the convex spheric, and the concave conic surfaces to be formed, and the line drawn on the under side of any stone in each of the intermediate courses will be the arris between the convex conic and the concave spheric surfaces to be formed; that is, between the surfaces which will form the lower bed and a portion of the interior surface of the dome.

Draw the form of the section of the course upon the plane of the other joint, so that the corners of the quadrilateral figure thus drawn may agree with the four lines drawn on the two cylindric, and on the two parallel plane surfaces.

Lastly, reduce the stone to its ultimate figure by cutting away the parts between every two adjacent lines which are to form the arrises between every two adjacent surfaces, until each surface acquire its desired form.

Each of the spherical surfaces must be tried with a circular edged rule, in such a manner that the plane of curve must in every application be perpendicular to each of the arris lines, the mould for the convex spheric surface being concave on the trying edge which must be a portion of the convex side of the section, *fig.* 1, and the mould for the concave side convex on the trying edge, and a portion of the concave arc forming the inside of the section.

The two conical surfaces of the beds, and the two plane surfaces of the vertical joints, must be each tried with a straight edge, in

such a manner that the trying edge must always be so placed as to be in a plane perpendicular to each of the circular terminating arcs; so that the surfaces between these arcs must always be prominent until the trying edge coincide with the two circular edges, and every intermediate point of the trying edge with the surface.

Fig. 3, Let *Abcdef* . . . . Y, be the exterior curve of the section divided into the equal parts *Ab*, *bc*, *cd*, &c. at the points *b*, *c*, &c. so that each of the chords *Ab*, *bc*, *cd*, &c. may be equal to the breadth of the stones in each of the circular courses; also let *ghijkl* . . . . X, be the inner curve of the section, divided likewise into the equal arcs *gh*, *hi*, *ij*, &c., by the radiating lines *bh*, *ci*, &c.; hence *Abhg* is a right section of the first course; and, therefore, the figure of the joint at each end of every stone in the first course; likewise *bcih* is the right section of the second course; and, therefore, the figure of the joint at each end of every stone in the second course.

Since the entire exterior curve of the axal section of the dome is divided into equal parts alike from the basis on each side of the section; and since the exterior and interior sides of the section are each a semicircular arc, and described from the same centre; and since the dividing lines *bh*, *ci*, &c. radiate to this centre, all the sections of the courses, and the boundaries of the vertical joints will be equal and similar figures; and, therefore, a mould made to the figure of the section of any course will serve for the vertical joints of all the stones.

Fig. 4 exhibits one fourth part of the plan of the convex side of the dome showing the number of courses, and the number of stones in each quarter-course, there being three stones of equal length in each quarter-course.

In the first or bottom course, *mnop* is the plan of the convex side of one of the stones, and *m'n'o'p'* the plan of the concave side of the same stone; and, in the second course, *qrst* is the plan of the convex side of one of the stones, and *q'r's't'* is the plan of the concave side of the same stone; so that in the first course *mno'p'* is the figure of the top and bottom of one of the ring-stones, *po* is the intermediate line on the top, and *m'n'* that on the bottom, and so on for the remaining stones.

All the stones of any course being equal and similar solids, and alike situated, the same mould which serves to execute any stone of any one course will serve to execute every stone of that course; but every course must have a different set of moulds from those of another, except the figures of the vertical joints, which will be all found by one mould, as has been already observed.

The reader, who has a competent knowledge of the construction of niches in horizontal courses, will not be at any great loss to understand the construction of domes; or if the construction of domes is well understood, he cannot be at any loss to comprehend the construction of niches; however, as there are many observations respecting the construction of domes that do not apply to niches, particularly as the dome in the present article has two apparent sides, in order to prevent the reader from wasting his time in referring to both articles, we shall here conduct him through the formation of one of the stones in the first two courses, the figure of the stones in the remaining courses being found in a similar manner.

In *fig.* 3, draw AD perpendicular to the ground-line AY, and through *h* draw BC also perpendicular to the ground-line AY. Now AB as well as Ag being upon the ground-line, therefore to complete the rectangle ABCD, so as to circumscribe the section A*bhg*, and to have two vertical and two horizontal sides, draw through the point *b* the remaining side DC parallel to AY.

The rectangle ABCD is the section of a circular course of stone, or that of a ring contained by two vertical concentric uniform cylindric surfaces and by two horizontal plane rings, the radius of the concave cylindric surface being *a*B, and the radius of the convex cylindric surface being *a*A, and the height of the ring being AD or BC.

Make a mould to the plan of one of the stones in the first course, that is, to *mnop*, *fig.* 4.

From any point *y*, *fig.* 5, with a radius *zm*, *fig.* 4, or the radius *a*A, *fig.* 3, describe the arc *mn*. Make the arc *mn*, *fig.* 5, equal to the arc *mn*, *fig.* 4, and draw the lines *mu* and *nv* radiating to the point *y*. Again, from the centre *y*, and with the radius *a*B, *fig.* 3, describe the arc *ru*.

Make a face-mould to *mnvu*, and this mould will serve for drawing the figure of the two horizontal surfaces of each stone in the first or bottom.

To cut one of the stones in the first course to the required form:—Reduce the stone from one of the sides till the surface becomes a plane. Apply the mould made to the figure *mnvu* on this surface, which is one of the two horizontal faces, and having drawn the figure of the mould, reduce the stone so as to form three of the arris lines of the faces, which are to be vertical, and these arrises will be square to the face already wrought. On each of the three arrises thus formed, set the height of the stone from the plane surface already made; reduce the substance till the surface becomes a plane parallel to that first formed.

Apply then the face mould *mnvu*, upon the plane surface last wrought, so that three points of the mould may join the corresponding points in the meeting of the three arrises, and having drawn the figure of the mould upon the second formed face, run a draught on the outside of each line upon each of the intermediate surfaces from each of the parallel faces. So that there will be four draughts receding from the face first formed, and four receding from the face last formed, and that upon the whole, including the two draughts upon each side of each of the four perpendicular arrises, there will be sixteen in all.

The two draughts along the edges of the convex cylindric surface to be formed, must be tried with a concave circular rule, made to the form of the arc *mn*, *fig.* 4, and the two draughts along the edges of the concave cylindric surface, must be tried with a convex circular rule made to the form of the arc *po*, *fig.* 4. Moreover, the two draughts which are made along each of the edges of each opposite intermediate plane surface, must be tried with a straight edge.

Having regularly formed the draughts, so that the circular and straight edges of each of the three rules may coincide in all points with the bottom surface of each respective draught, and with the arris line at each extremity, the workman may then cut away the superfluous parts of the stone, as far as he can discern to be just prominent, or something raised above the four draughts, bordering the four edges of each of these surfaces.

The rough part of the operation being done, each of the four intermediate faces may be brought to a smooth surface and to the required form, by means of a common square; the face of coincidence of the stock, or thick leg, being applied upon one of the two parallel faces, and the thin leg, called the blade, to the surface of the stone, in the act of reducing, until it has acquired the figure desired, or the two cylindric surfaces may also be tried by means of circular edged rules, the edge of each rule being placed so as to be parallel to one of the parallel faces; a concave circular edge being applied upon the convex side, and a convex circular edge upon the concave side.

The six faces which contain the solid being thus formed, we shall now proceed to find the upper arris:—for this purpose apply the mould made to the form *mnop*, *fig.* 4, upon the top of the stone drawn by the means of the mould *mnvu*, *fig.* 5.

Suppose *mnvu*, *fig.* 5, to be the figure drawn on the top of the stone itself, by means of the mould made to *mnvu*; and *mnop*, *fig.* 5, to be the mould made from *mnop*, *fig.* 4. Lay the edge *mn*, *fig.* 4, upon the edge *mn*, *fig.* 5, on the top of the stone, so that the equal circular arcs may coincide in all their points; and draw the line *op* along the concave edge of the mould, and *op* will be the arris line of the spherical and conical surfaces which are yet to be formed.

Let the rectangle *mnn'm'*, *fig.* 6, be the elevation of the convex cylindric surface of the same stone, projected on a plane parallel to each of the chords of the circular arcs, and to one of the straight arrises of this surface; the straight line *mn* representing the upper circular edge, *mm*, *nn'* the two vertical arrises; so that the convex spherical surface is terminated at the top by the arc *op* and at the bottom by the arc *n'm'*.

Let the rectangle *nmm'n'*, *fig.* 7, be the elevation of the concave cylindric face projected on a plane, parallel to one of the chords of one of the circular boundaries, and to one of the straight-lined boundaries of this face; then the upper and lower planes will be projected into the parallel lines *nm*, *n'm'*. Therefore all the lines of each of these three planes will be projected upon the lines *nm*, *n'm'*, and as the rectilineal figure formed by the two chords and the two straight lines is parallel to the plane of projection, it will be projected into an equal and similar figure; therefore the projected figure is a rectangle, and the sides *nm*, *n'm'* are equal to each other, and to the chords of the two circular arcs; and the lines *m'm*, *nn'* are each equal to the height of the hollow cylinder, or equal to the distance between the parallel planes.

Hence the concave surface will be projected also into a rectangle, and the middle of the chords of the arcs terminating the parallel edges of the concave surface upon the middle of the chords of the arcs, terminating two of the opposite edges of the convex surface, as also the two opposite parallel straight-lined sides in the height of the solid, will be projected into straight lines equidistant from the projections of the corresponding lines in the height of the solid on the convex side.

Therefore, the straight lines *nn'*, *mm'*, *vv'*, *uu'*, are all equal to the height of the hollow cylindric solid, or equal to the distance between the parallel planes and the distance between the lines *nn'*, *vv'*, equal to the distance between the lines *mm'*, *uu'*.

To form the common termination between the upper conical and the lower spherical surfaces, let *vv'*, *u'u*, represent the concave cylindric surface; and, therefore *vv'*, *uu'*, will represent the opposite circular arcs, which terminate two of the sides of this concavity. Upon this surface draw the lines *v'' u''*, parallel to the circular edge *vu*, on the top at the distance *h*C, *fig.* 3, and the line *v''*, *u''* will be the arris now required between the concave conic surface at the top, and the concave spheric surface. These two surfaces being as yet to be formed.

To form the remaining and common termination of the concave spherical surface, and the lower or level bed of the stone:—Draw a circular arc on the level surface, underneath parallel to the circular, to the circular edge on the lower edge of the concave cylindric surface, and this line will be the remaining arris required.

The two cylindric surfaces, and the upper plane surface, are entirely cut away; but the intermediate line drawn on the top, and that drawn on each cylindric surface, remain, as well as the outer edge of the lower bed.

To form the intermediate faces of the stone, into the two upper and lower conical beds, and into the two apparent concave and convex spherical surfaces: Reduce each side of the solid as near to the required surface as possible, so that all the intermediate parts between the arrises or lines drawn on the former faces, may be prominent.

Suppose then, that we proceed to finish the stone required to be formed, in the following order: first, by proceeding with the convex spherical surface; secondly, the upper concave conical surface; thirdly and lastly, the concave spherical surface. Having approached as nearly to the required surfaces as can be done with safety, the upper conical concave surface will be reduced to its ultimate form by cutting away the substance carefully, so that the surface between the two arris lines may at last coincide with all the points of a straight edge applied perpendicularly to the two arrises.

The convex spherical face will be formed ultimately by cutting the substance of the stone carefully, so that the surface between the arris-line on the top, and the circular convex arris-line on the outside of the lower bed, may at last agree with all the points of the circular concave edge of the rule made to a portion of the arc *Abcd*, *fig.* 3, of the section of the dome. This circular edged rule must be frequently applied; and in each application the plane of the arc must be perpendicular to the surface, gradually approaching to its required sphericity.

To form the concave surface of the upper bed of the stone, reduce the solid by carefully cutting parts away, so as at length the surface between the upper arris and the intermediate line drawn on the inside formerly concave, may coincide with all the points of a straight edge applied perpendicularly to the upper arris-line from any point of this arris.

The concave spherical surface will be formed in the same manner as the convex spherical surface already supposed to be formed, with this difference, that the circular edge which proves the sphericity, by trial must be convex instead of being concave. This convex surface lies between the lower arris, terminating the upper conic bed, and the inner arris of the lower bed.

As to the lower bed it is already formed, being part of the plane surface,

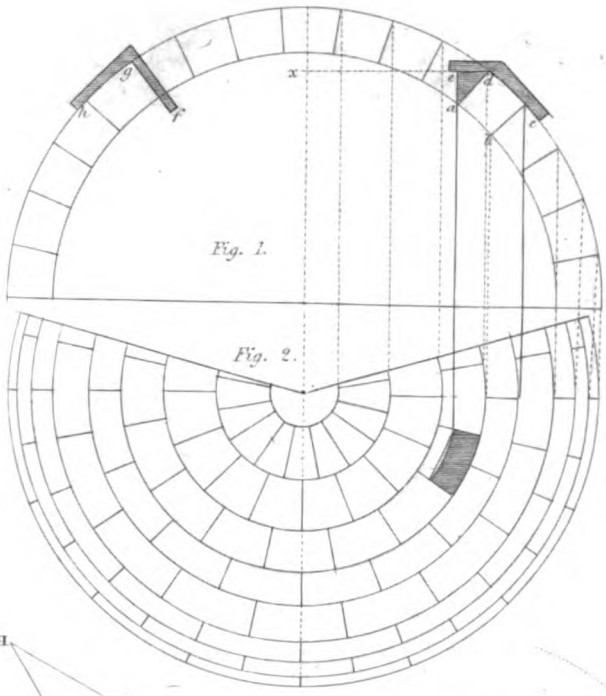
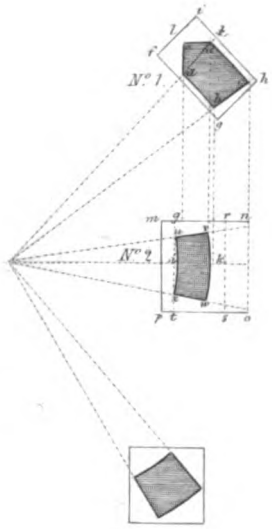


Fig. 1.
Fig. 2.


N° 1
N° 2

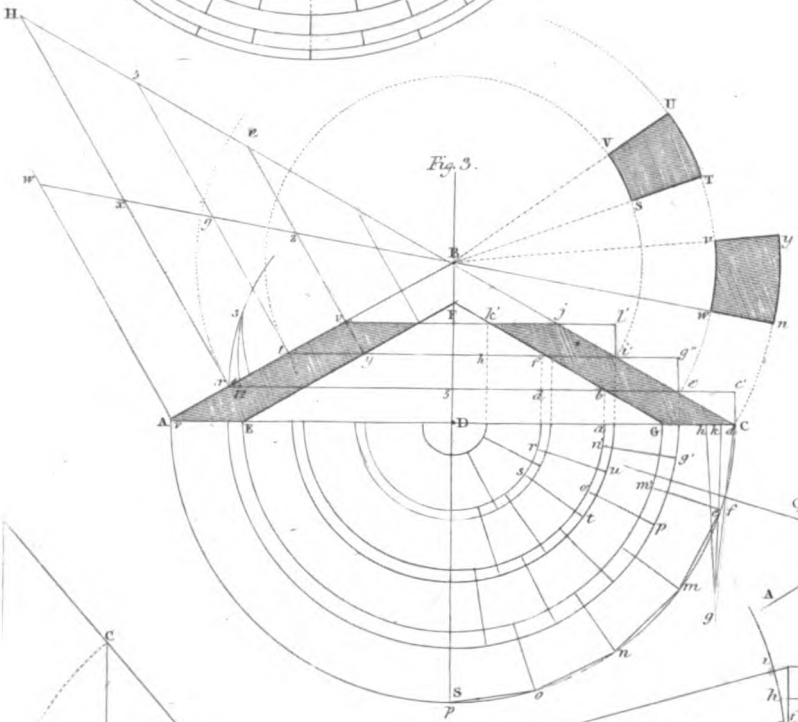


Fig. 3.

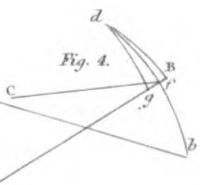


Fig. 4.

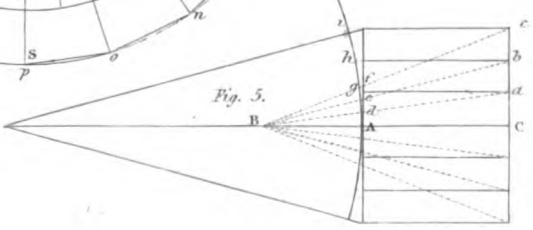


Fig. 5.

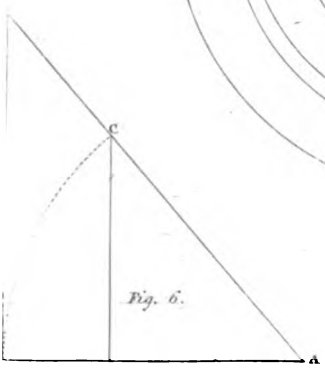


Fig. 6.

formerly one of the ends of the hollow cylinder, in a plane perpendicular to the common axis; and as to the ends forming the vertical joints, they were at first formed in making the hollow cylindric solid; so that one of the stones in the lower course is now finished.

One of the stones in the second course being first formed into the frustrum of a cylindric wedge, as was done with the stone formed for the first course, the several faces which contain this solid are as follow:—*grxw*, *fig.* 5, represents the plane truncated sector forming the top, *st* being the arris-line between the spheric surface on the convex side of *st*, and the conic surface in the concave side of *st*; *grr'g'*, *fig.* 8, the convex cylindric surface, *g''rn''* the arris between the convex spheric and the convex conic surfaces, and *r'ggr'*, *fig.* 9, the concave cylindric surface; *x''w''*, the arris between the concave spheric surface underneath and the concave conic surface above, the arris-line being drawn upon the lower plane surface, we shall thus have the arris-lines between the spheric and conic surfaces.

The solid being cut as before directed between the arris-lines until the surfaces are duly formed, we shall have also one of the stones in the second course completely prepared for setting.

Perhaps for preparing the stones for the first and second courses, as also the stones near the summit, no better method can be followed than that which we have employed in preparing a stone in each of the two lower courses, yet as the saving of an expensive material and labor is a desirable object, we shall here show how the waste of stone and the labour of the workman may in a considerable degree be prevented.

PLATE XXIV. ANOTHER METHOD.

Let *fig.* 1 be the section of the dome, and *fig.* 2 a plan of the same, showing the convex side. Now as the saving of material will be principally in the stones which constitute the intermediate courses, we shall select, for an example, the fifth stone from the bottom and from the summit. The section of this stone is *abcd*, *fig.* 1.

Draw *de* parallel, and *ae* perpendicular to the base of the dome. Then instead of first working the sides of the stone, so that the section may be a rectangle, of which two sides are parallel and two perpendicular to the horizon; let it be wrought into the form *abcde*, so that the part *de* may be parallel to the horizon.

Let the section *abcde* be transferred to No. 1, at *abcde*, and let *fghi*, No. 1, be the section of the rough stone, out of which the coursing-stone of the dome is to be wrought; the sides of the section of the rough stone having two parallel and two perpendicular faces to the lower bed of the stone. The wrought stone must be selected sufficiently large, so that, when it is reduced to the intended form, all the spherical and conical surfaces must be entire, and thus the arrises will also be entire.

The first operation is to reduce the stone by taking away a triangular prism from the top; the section of which prism is represented by *kli*, No. 1, so that the surface of which the section is *de*, may be a plane surface.

No. 2 is an orthographical projection of the stone, of which the section is *mnop*, after being thus reduced, *grst* representing the plane surface, of which the section is *kl*, No. 1, is parallel to the plane of projection. On the plane surface *grst*, No. 2, apply a mould *xuvw*, so that the radius of the curved edge *uv*, may be equal to the line *dx*, *fig.* 1, *dx*, being parallel to the base, meeting the axis in *x*, and that *vu* and *wx* may be straight lines tending to the centre of the arc *ux*; and that the chord of the arc *ux* may be equal to the length of the chord of the upper arris of stone. Draw lines along *xu*, *uv*, and *wv*, of the mould, and let *vw* be the line drawn by the curved edge *vw* of the mould, *uv* the line drawn by the straight edge *uv* of the mould, and *xw* the line drawn by the straight edge *xw* of the mould.

Take the mould away, and there will remain the three lines viz. the arc *vw*, and the straight lines *vu* and *wx*, which radiate to the centre. Then *vw* is the upper arris of the stone, and the straight lines *vu* and *wx*, as in the planes of the meeting joints of the two adjacent stones in the same course to that which is now in the act of working.

The second operation is to work the spherical surface by means of the bevel *edc*, *fig.* 1, in such a manner, that while the point *d* is upon any point of the arc *vw*, No. 2, the straight edge *de* may coincide with the plane surface *xuvw*, No. 2, and the curved edge *dc* may coincide with the spherical surface required to be formed, and lastly, that the plane of the bevel *cde* may be perpendicular to the arris line *vw*.

The third operation is to find the vertical joints of the stone: these will be formed by means of a common square, of which the right angle is contained by two straight lines, so that when the vertex of the angle of the square is upon any point of the line *vw* or *ux*, No. 2, the inner face of application of the third part must be upon the plane surface *tuvw*, and the edge of application of the thin part upon the vertical joint, and that both edges of application may be perpendicular to the line *vw* or *ux*.

The fourth operation is to form the conical upper bed of the stone by means of the bevel *fgh*, *fig.* 1, so that when this conic surface is wrought to the required form, and the vertex *g* of the angle is applied upon any point of the curve *uv*, No. 2, the curved edge *gh* may then coincide with the spherical surface, and the straight edge *gf* with the conical bed thus formed, the edges *gf* and *gh* being perpendicular to the arris *ux*.

Thus four sides of the stone are now formed, viz. the convex spherical surface, the concave conical surface, and the two vertical joints of the stone. By gauging the spherical surface to its breadth, the under or convex conical surface may be formed by means of the same bevel *fgh*, *fig.* 1, and gauging the sides of the stone which form the joints, viz. the concave and convex conic surfaces which form the upper and lower beds, and the two vertical joints from the spherical convex surface, we shall now be enabled to form the concave spherical surface by means of a slip of wood, of which one edge is formed to the curve of the inside of the section, No. 1, and thus we have formed a stone of the fifth course, as required to be done. In the same manner the stones of every course may be formed.

This method will never require so much stone as the former or first method, nor yet the quantity of workmanship; but it requires greater care in the execution. This last method was used in the construction of the dome of the Hunterian Museum at Glasgow.

To execute a vault, of which both the extrados and intrados are conic surfaces, having a common vertical axis, the solid being equally thick between the conic surfaces, so that in the joint lines those of beds may be horizontal, and those of the headings in vertical planes passing along the axis.

The easiest method of executing this, is to form the beds so that when built they will unite in horizontal planes, and the headings in vertical planes.

Let ABC, *fig.* 3, be a section of the exterior surface, and EFG a section of the interior surface; the lines AB and EF being parallel, as also the lines CB and GF.

In order for the easy application of the bevels, it will be convenient to work the exterior faces of the stones first as plane surfaces; then form the joints by means of a face mould, and the angles which the joints make with the planes of the faces by means of the bevels, and lastly, run a draught upon each end of the face first wrought according to the proper curve of the cone.

Let *d*S*v* be the exterior line of the plan, D being the centre of all the circles which form the seats of the joint lines in the plan. Divide the semi-circular arc *d*S*v* into as many equal parts as the number of vertical joints in the semi-circumference.

Let there be five stones, for instance, in each quadrant; therefore, if *d*S and S*v* be quadrants, divide *d*S into five equal parts, and let *de* be the first part. Through the point *e*, draw the radius *f*D. Bisect the arc *de* in *f*, and draw C*f* a tangent to the semi-circular arc *d*S*v* at the point *f*. Bisect each of the arcs between the points of division in the quadrantal arc *d*S, and the tangents being drawn at each point of bisection, will form the polygonal base C*fmnop*.

To form the angle of the mitre at the meeting of two heading joints. In C*f*, or C*f* produced, take any point *g*, and draw *gh* perpendicular to the diameter AC, meeting AC in the point *h*. Draw *hi* perpendicular to CB, meeting CB in the point *i*. In DC make *hk* equal to *hi* and join *kg*; then will the angle D*kg* be the bevel of the mitre.

The sections of each of the stones as they rise, being *de*b'G', $e'i'f'b'$, $i'j'k'f'$, the dimensions of the stones will be found as follows. Through the points e', i', j', draw the straight lines $d'c$, $h'g'$, $k'l'$, intersecting the inner line GF in the points b', f', k'. Through b', f', k', draw the lines ab', $d'f'$, $h'k'$, perpendicular to AC. Also through the points e', i', j', draw $e'g'$, $i'l'$, as also Cc, which will complete the sections of the stones. The other side, AEFB of the section, exhibits the sections of the stones perpendicular to the intrados and extrados of the lines; the sections of the stones being AE*r*, Eβ*r*, βyV*t*, and the sections of the joints E*r*, βt, yV. To find the curve of the stone at any section as E*r* at the point *r*. With the horizontal radius 5*r*, *fig.* 3, and from the centre 5, describe an arc *r*3. From the point 3, draw 32 perpendicular to 5*r*, meeting 5*r* in 2. In 2*r* make 21 equal to the nearest distance between the point 2 and the line AB. From some point

found in the line 5r, describe an arc 13, and the arc 13 will be the curvature of the top of the stone at the joint. This is shown at *fig.* 4.

Figs. 5 and 6 exhibit another method of finding the curve at the joint, by means of the radius of curvature.

SECTION XIII.

CONSTRUCTION OF THE MOULDS, AND FORMATION OF THE STONES, FOR RECTANGULAR GROUND VAULTS.

CONSTRUCTION OF GROINED VAULTS, CYLINDRETIC SURFACES.

A CYLINDRETIC surface is every surface which may be generated by a straight line moving parallel to itself, and intersecting a given curve line.

Since, in good masonry, the sides of the joints of any course of a vault are made to terminate upon the intrados, in a horizontal plane perpendicularly to the intrados, if the intrados be a cylindric surface, of which the sides are straight lines parallel to the horizon, the sides of the coursing joints will be in planes intersecting the intrados, perpendicularly in straight lines, and the course will form one prismatic solid; hence all the right sections will be equal and similar figures, and will be in vertical planes.

The stones of a groin, which have any difficulty in their construction, are those at the meeting of two adjacent sides, and it is only the formation of these which we shall describe.

In order to form the stone of any course, circumscribe a rectangle round each corresponding right section of the course, so that the sides of the rectangle may each pass through the point of meeting of every two sides of the section of the course, and that two of these sides may be parallel, and two perpendicular to the horizon, as was done in respect of the execution of niches in horizontal courses, and in the formation of the stones of a dome.

In the first place, the stone must be squared in such a manner, that every two faces which meet each other may form a right angle, and that two of the faces may be parallel and six perpendicular to the horizon, and that only two of the six faces which are perpendicular to the horizon may form a receding angle; and, moreover, that the figure of the two faces which are parallel to the horizon may be formed to the plan of the stone, as formed by the rectangular planes.

The two vertical faces which form a right angle with each other, but which do not join in consequence of the two vertical faces which form the receding angle coming between them, are those two faces in the plane of the vertical joints.

The figures of these faces must be made to the rectangle, circumscribing each respective section.

The next operation is to gauge two lines on the upper level surface, so as to form the return arris between the upper bed and the con-

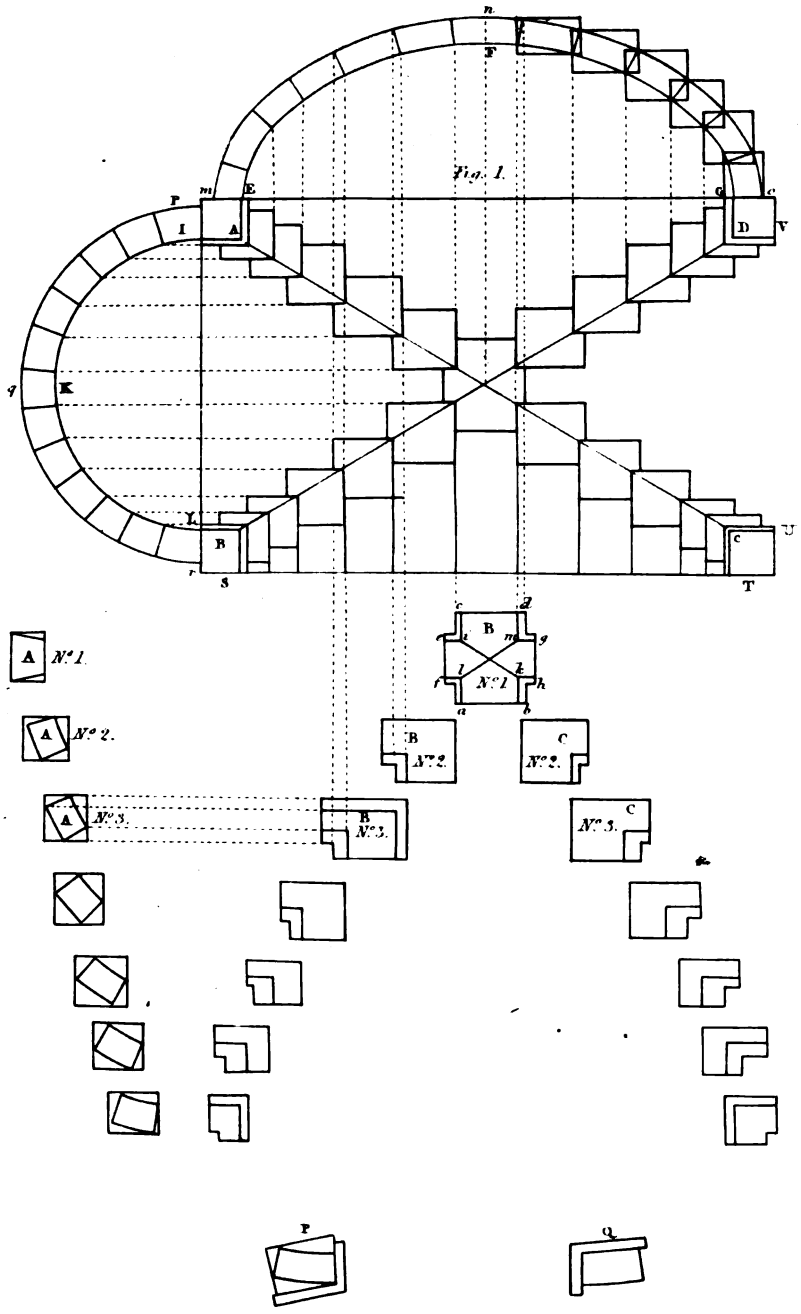


Fig. 1.
A N°1.
A N°2.
A N°3.
B N°1
B N°2
B N°3
C N°2
C N°3
P
Q

vex cylindretic surface on each side of the groin ; this operation being done, gauge two lines on the lower level surface, so as to form the return arris between the lower bed and the concave cylindretic surface on each side of the groin. These two lines will thus form a right angle, which being drawn, gauge a line upon each of the vertical sides which form the internal right angle, and these lines will be the arris of the stone on each side of the groin between the upper bed of the stone and the concave cylindretic surface ; and, lastly, gauge a line upon each of the vertical surfaces which are opposite to those forming the internal angle, so that each of the two lines thus drawn may form the arrises between the convex surface and the lower bed.

The arrises of the stone being thus drawn, it must be reduced to such surfaces, that each of the lines may be the arris of every two adjacent surfaces.

The two beds of the stone are plane surfaces, and are therefore formed by means of a straight edge. The other cylindretic surfaces are brought to form by means of a curved edge made to the place where the stone is to be set. It is evident that when the curve varies, a mould must be made to every stone.

Fig. 1, *Plate* XXV, is the plan of a ground vault with its vertical right sections upon each side of it. In the plan A,B,C,D, exhibit the springing points of the groins, AC and BD are the plans of the groins, or intersections of the cylindretic surfaces. These plans of the surfaces of the stones in the intrados, which form the ground angles, are exhibited along the lines AC, BD.

IKL is a section of the intrados, and *pqr* a section of the extrados, the intrados and extrados being concentric semi-circular arcs; EFG and *mno* are sections of the intrados and extrados of the other vault, being each a surbased semi-elliptic arc, equal in height respectively to the semi-circular arcs of the other vault.

These two sections of each vault exhibit the section of each course of stone, with the circumscribing rectangle. These stones are exhibited separately at No. 1, No. 2. No. 3, &c.

No. 1 is that over the centre of the section of the semi-circular vault; No. 2, that next to the stone over the centre; No. 3, the second stone from that over the centre ; and so on.

No. 1, A, is a section of the course, or of a stone over the centre of one of the semi-circular branches of the groined vault, showing the circumscribing rectangle; and No. 1, B, is the underside of the same stone, forming a part of the intrados of the vault. This exhibits the stone as if squared with the portions of the plans of the groins, which are to be wrought on this stone, as also the plans of the intersections of the joints with the upper surface or intrados.

Having wrought a concave draught along the lines *ab*, *cd* to the middle of the intrados EFG of the section of the elliptic vault, the intermediate surface between *ab* and *cd* may be formed by means of a straight edge applied parallel to *ac* or *bd*, and having wrought the concave draught along the lines *ef gh*, so that the points *e*, *f*, *g*, *h* may remain, while the intermediate is sunk, and so

that the draught thus sunk, may have the same curve as the intrados line IKL of the semi-circular branch. The intermediate part may be formed by means of a straight edge applied parallel to *eg* or *fh*, and thus the two cylindretic surfaces crossing each other will form the groins *ik*, *lm*, which belong to the central stone, and which are a portion of the whole groins resting on the springing points.

These arrises being formed by the intersection of the cylindretic surfaces, which meet each other at very obtuse angles, ought to be done with care, otherwise the beauty of the intersections would be destroyed.

No. 2, 3, &c. require a similar description to that of No. 1, and therefore will be sufficiently understood from that now given.

P and Q exhibit the manner of forming one of the stones agreeable to the section of one of the elliptic branches of the groined vault after having squared the stone, this stone being supposed to be the second from that over the centre.

It is worthy of notice, that except the stone in the summit of the groined vault, any four stones equally distant from the centre of the ground ceiling, though reduced by the same moulds to the same number of similar surfaces, and though every two corresponding similar surfaces meet each other; yet nevertheless any one of the four stones can only fit one of the four situations; so that the same moulds will serve for the formation of four stones equally distant from the summit.

SECTION XIV.

THE MANNER OF FINDING THE SECTIONS OF RAKING MOULDINGS.

To find the raking mouldings of a canted bow-window, with munions and transoms.

Let the plan of the window be *fig.* 1, *Plate* XVI, consisting of three sides, the middle one being parallel to the walls, and the other two at an angle of 135 degrees each, with the middle face of the window.

Also, let *ra*Q, *fig.* 2, be a horizontal section of one of the angles, No. 1 being a right section of one of the munions, the same as the right section of the transom sill or lintel, and let *ar*, No. 2, be the line of mitre corresponding to AR, No. 1, AR being perpendicular to *a*Q.

In order to find the right section, No. 2, of the angular munion. In the curves of the given section, No. 1, draw lines through a sufficient number of points perpendicular to *a*Q, and draw *ac* perpendicular to *ar*; transfer the points B C from A, No. 1, made by the perpendiculars to No. 2; from *a* to *c* upon *ac*, and from *a* to *b* through the points *b c* draw lines parallel to *ar*, to intersect the corresponding lines parallel to Q*a* from the assumed points K, L, M, N, in the curves, No. 1, and through these points trace the curves which will form one side of the section, No. 2; repeat the same operation on the other side, and we shall have the complete section required.

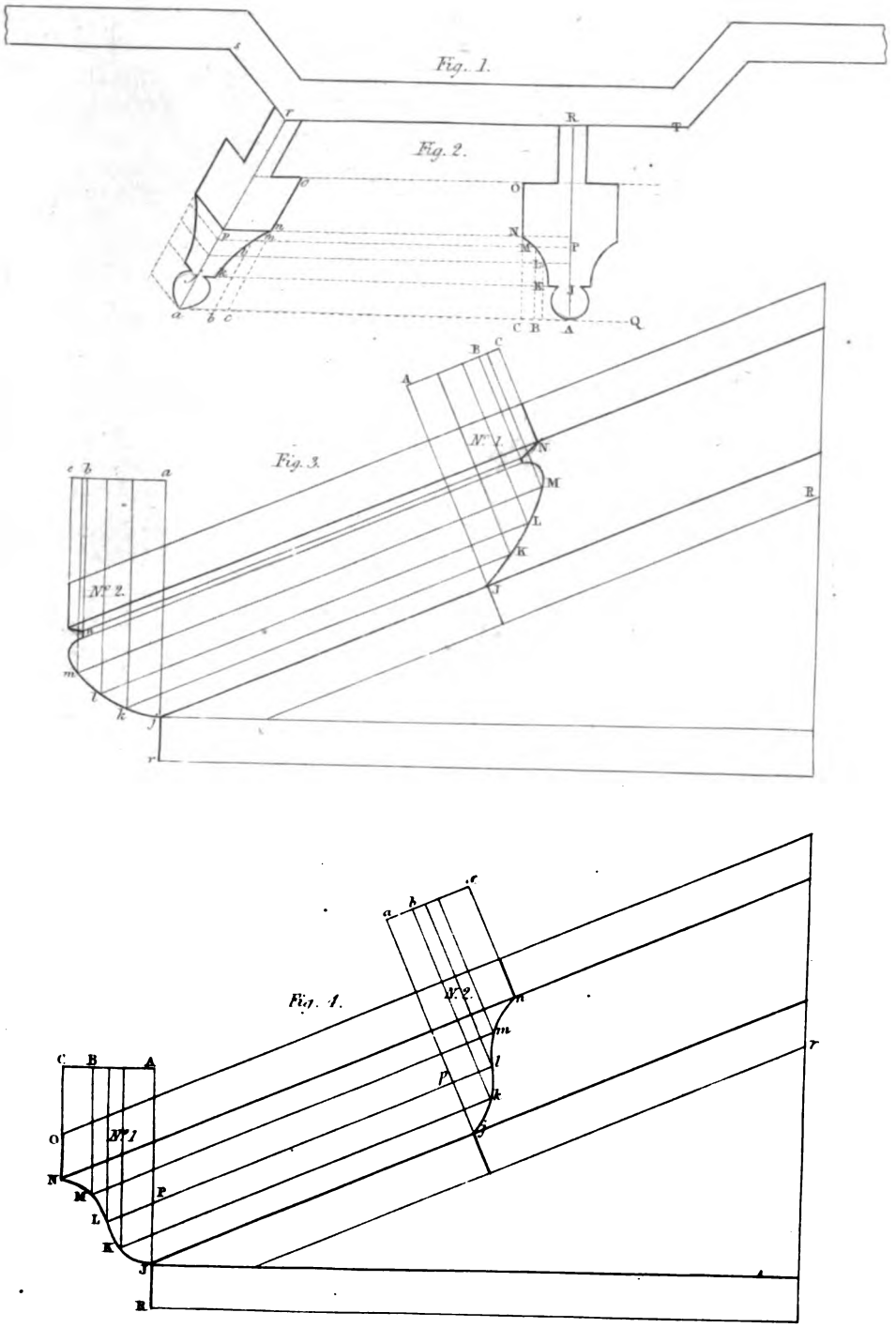
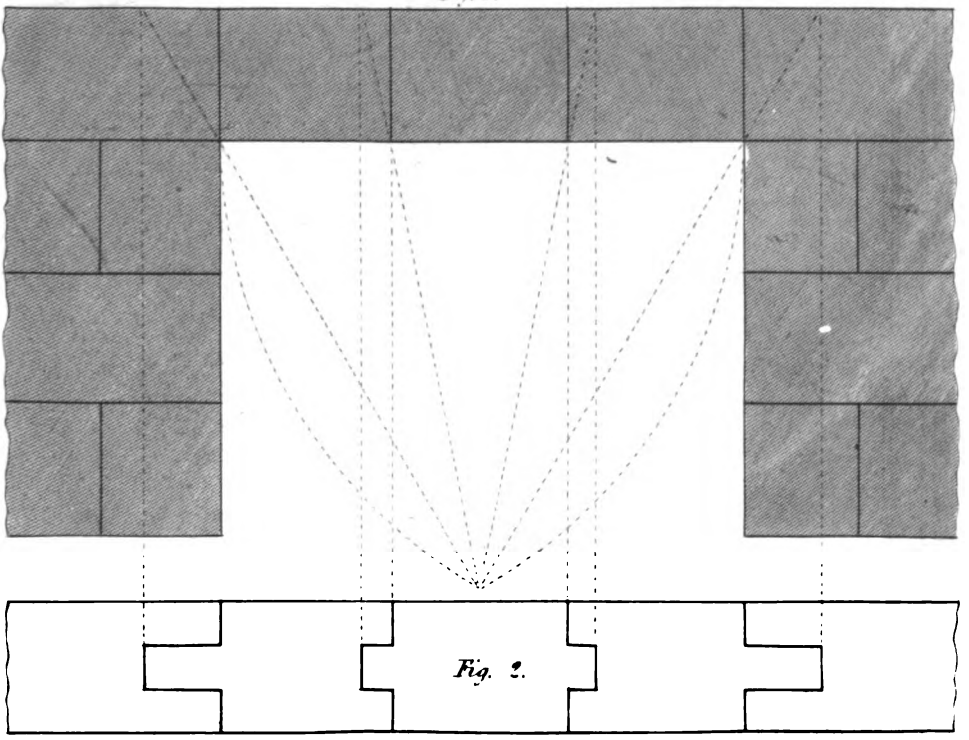
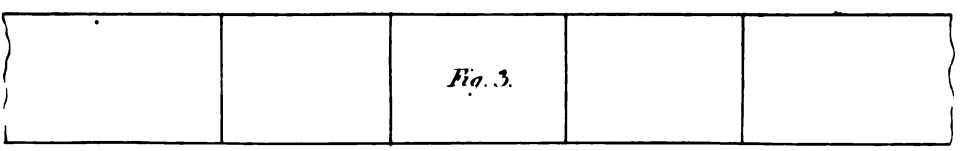
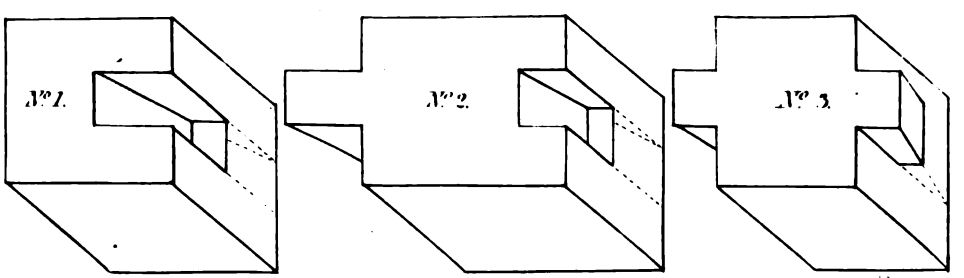


Fig. 1.
Fig. 2.
Fig. 3.
N° 1.
N° 2.
Fig. 4.
N° 1.
N° 2.

Fig. 1.







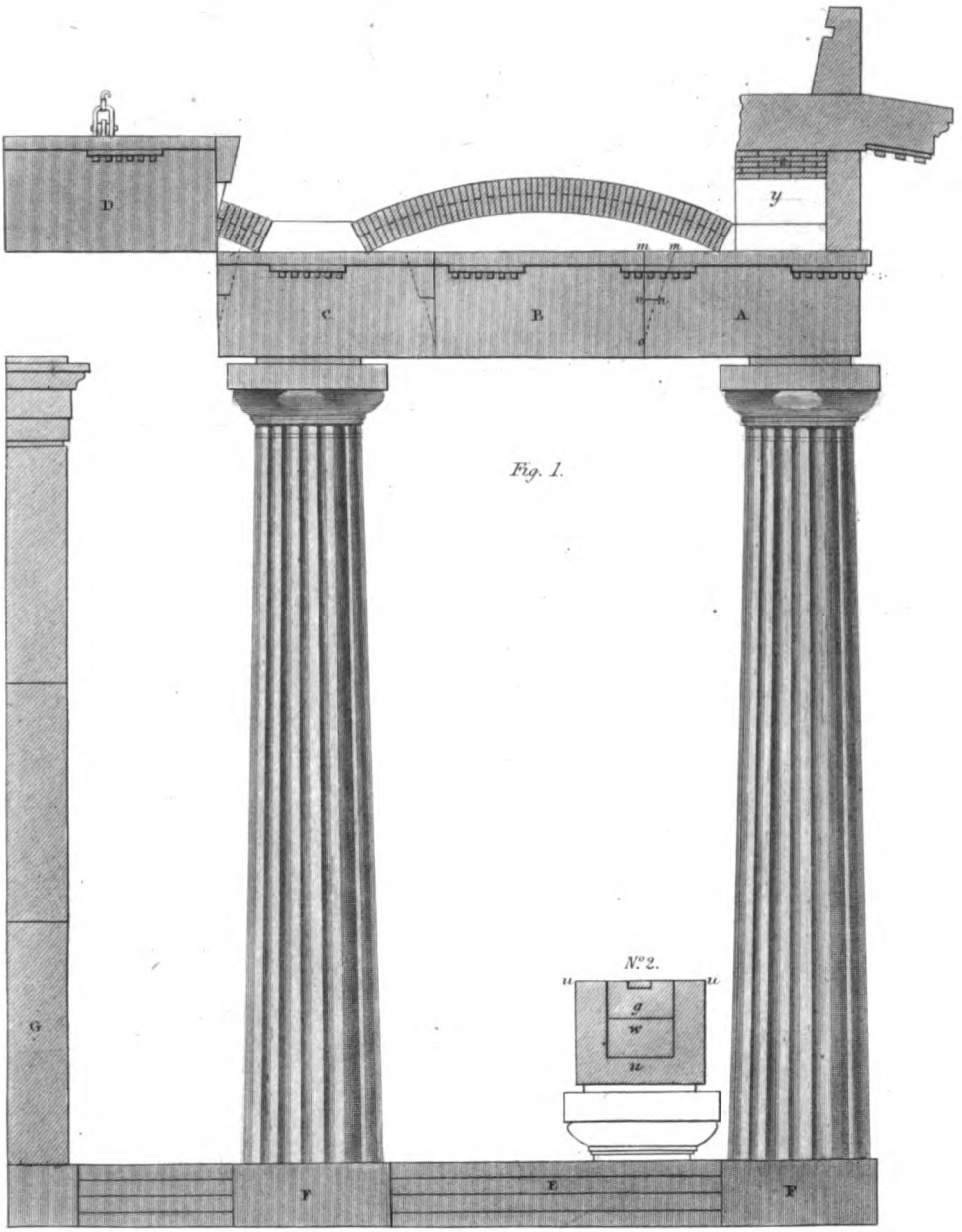
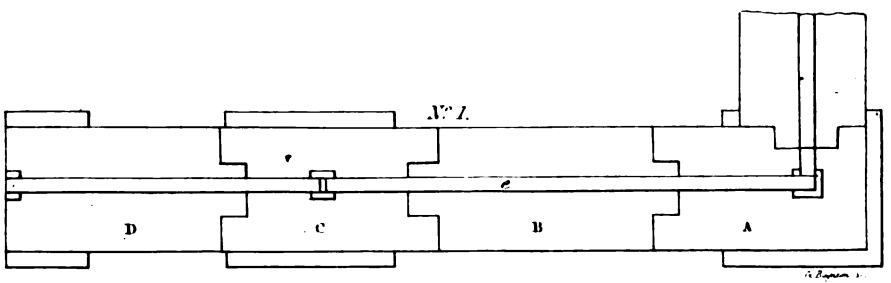


Fig. 1.

N° 2.



Figs. 3 and 4, No. 1, is the right section of the raking moulding on a pediment, which if supposed to be given, the section No. 2 may be found as that at No. 2, from No. 1, *fig.* 2; but in this case No. 2 is generally that which is given, and the section No. 1 is traced therefrom.

In all these cases of raking mouldings, draw *ac* perpendicular to *ar* the line of mitre. To find any point *m*, take the point M in the section No. 1, and draw MB perpendicular to AC, Nos. 1 and 2, meeting AC in B, and draw M*m* parallel to R*r*. Make *ab* equal to AB, and draw *bm* parallel to *aj*, and *m* will be a point in the curve. In the same manner will be found the points *j*, *k*, *l*, *n*, No. 2, from the points J, K, L, N, No. 1; and hence the section No. 2 may be traced from No. 1.

Fig. 4 is described in the same manner as *fig.* 3.

SECTION XV.

CONSTRUCTION OF A LINTEL, OR AN ARCHITRAVE, IN THREE OR MORE PARTS, OVER AN OPENING, AND THE STEPS OF A STAIR OVER AN AREA.

On the method of building a lintel, or architrave, with several stones, so that the soffit and top of the lintel, or architrave may be level; and that the connecting joints of the course may appear to be vertical in the front and rear of the lintel, or architrave.

A lintel, or architrave, is frequently formed in several stones, from the difficulty of procuring one of sufficient length. The method of doing this is founded upon the principle of arching, the arch being concealed within the thickness of the stones.

Fig. 1, *Plate* XXVII, represents the upper part of an aperture, linteled as specified in the contents of this chapter; the centre of the radiating joints being the vertex of an equilateral triangle.

Fig. 2 represents the top of the lintel, exhibiting the thickness of the radiating joints, and the thickness of the square joints on each side of the concealed arch.

Fig. 3 represents the soffit of the lintel, exhibiting the joint lines perpendicular to the two edges, as the radiating as well as the vertical joints, all terminate in these lines.

No. 1 exhibits the first abutment-stone over the pier; No. 2, the first stone of the lintel; No. 3, the second stone, which forms the key; the two remaining stones are the same as the first stone of the lintel, and the abutment-stone being placed in reverse order.

The three stones here exhibited, show the manner of indenting the stones so as to form a series of wedges; and in order to regulate the soffit, the radiations are stopped at half their height.

Fig. 1, *Plate* XXVIII, exhibits the method of constructing an architrave over columns when the stone is not of sufficient length to reach the two columns. No. 1, Plan of the upper horizontal side of the architrave exhibiting a chain-bar of

wrought-iron, with collars let in flush with the top bed, the sockets being filled with melted lead round the collars.

In the plan and elevation, the same letters express different sides of the same parts; thus in the elevation, *fig.* 1, the letter A is written upon the part expressing the vertical face of the stone, over the angular column; and A on the plan No. 1, expresses the horizontal side or bed of the same stone. The letter B, on the elevation *fig.* 1, represents the vertical face of the middle stone of the architrave; and B, on the plan, represents the bed of the middle stone. The letter C, on the elevation, represents the vertical face of the stone over the second column; and C represents the upper horizontal surface or bed. The stones A and C serve as abutments to the middle stone B, which is let in in the manner of a keystone, and therefore acts as a wedge. In order to lessen the effect of the pressure of the inclined sides from forcing the columns to a greater distance, the joint *onnmm* has two horizontal ledges, *nn*, *mm*, which will prevent the middle part from descending.

D exhibits a stone in the act of setting, and is let down by means of a lewis; a brick arch is exhibited over the architrave, in order to discharge the weight from above, and is resisted by the abutments at the ends. The lateral pressure of the brick arch, and of the stone B, is entirely counteracted by means of the chain-bar, of which the top is represented in No. 1.

No. 3, exhibits a section of the work, z being a section of the arch in the middle, and *y* shows the void between. The right section through the middle of the arch between the columns, is the same as shown at *yz*.

No. 2, exhibits the manner of cutting the joints of the stones over the column *g* and *w*, being the steps of the socket and *uuu* the square part of the joint.

On the construction of stairs over an area to an entrance door.

Stairs of this description, which consist of one flight, must either be supported upon a solid foundation raised from the ground; or, if over a hollow, the steps must be supported upon a brick arch, or otherwise, by working the soffits in the form of a concave curve.

FF, represents the abutments of the columns; E, the steps; G, the cantae as projecting from the wall, to support the architrave-stone D.

Since the joints should always be perpendicular to the curve, they must all tend to the centre of the circle which forms the soffit; and since the steps should rest firmly upon one another, they ought to rest upon a horizontal surface. To accomplish these ends, every joint between two steps ought to consist of two surfaces, one horizontal, and the other part a plane, radiating to the axis of the cylinder, of which the soffit of the steps is the curved surface.

Fig. 2, *Plate* XXIX, is the plan; *fig.* 1, the elevation of a semi-circular arched door-way, built of wrought stone with steps, and *fig.* 3, a section of the same; *ab* is the curve-line, representing a section of the soffits. The joints are here drawn to the centre *c* of the arc *ab*.

In this case, where there are no brick arches below, the joints should be plugged. *Fig.* 4 exhibits a section of the steps, showing the plugs, one in each end perpendicular to the surface of the joint.

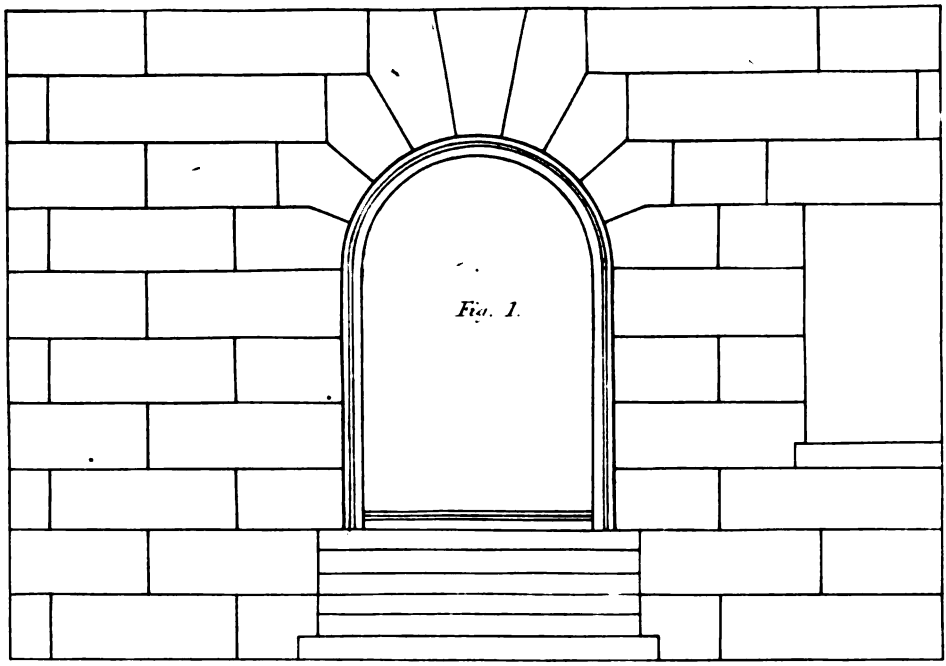


Fig. 1.

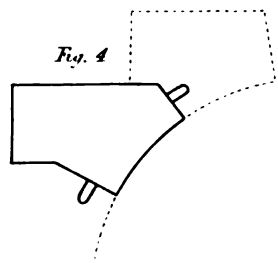


Fig. 4

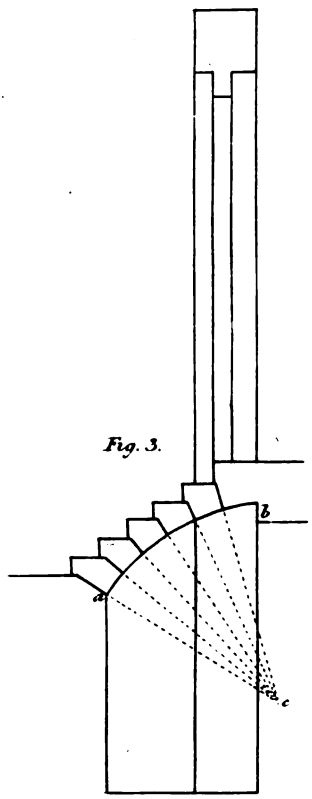


Fig. 3.

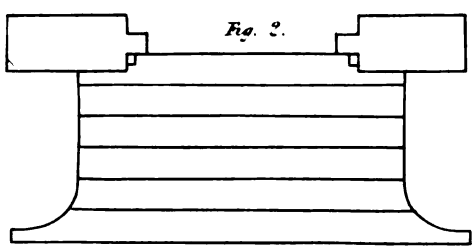


Fig. 2.

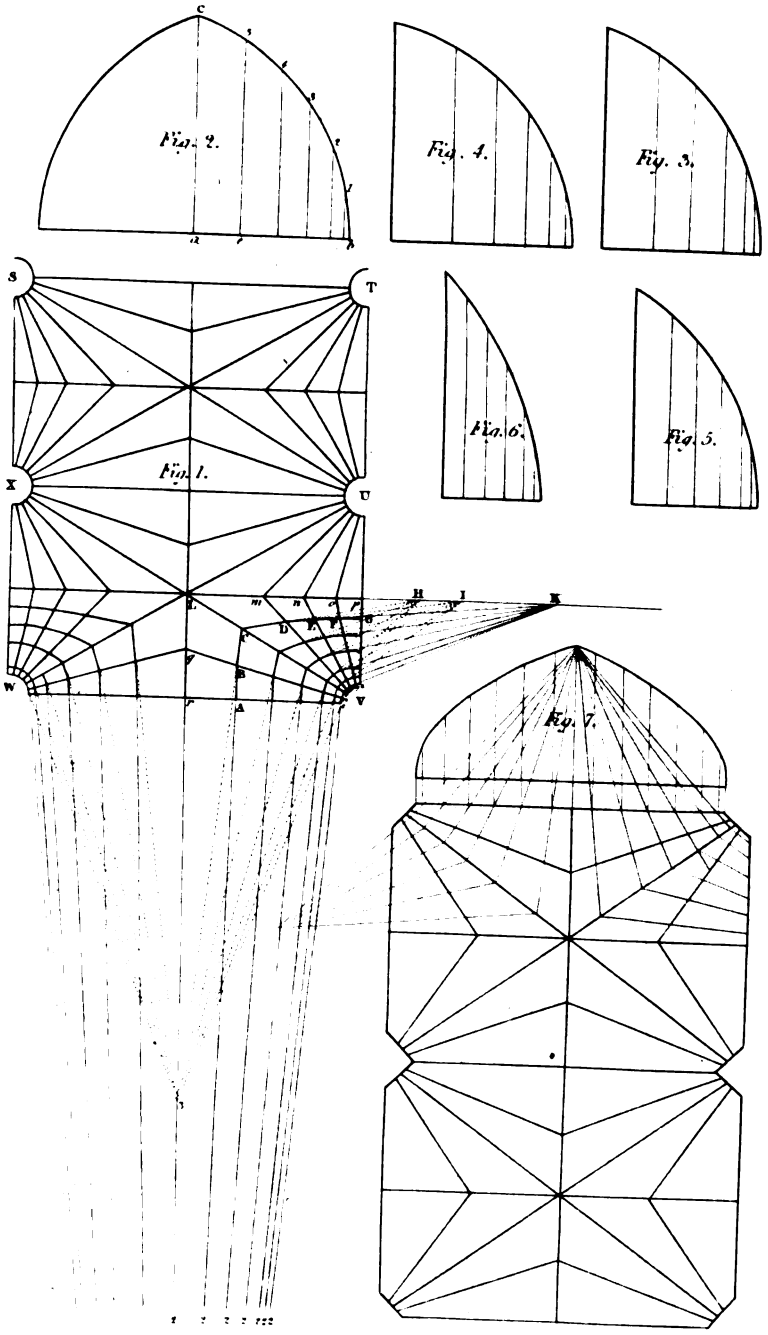


Fig. 2.
Fig. 4.
Fig. 3.
Fig. 1.
Fig. 6.
Fig. 5.
Fig. 7.

SECTION XVI.

CONSTRUCTION OF THE STONES FOR GOTHIC VAULTS, IN RECTANGULAR COMPARTMENTS UPON THE PLAN.

GROINED ARCHES SPRINGING FROM POLYGONAL PILLARS.

To execute a ribbed-groined ceiling in severies, upon a rectangular plan, so that the ribs may spring from points in the quadrantal arc of a circle, of which the centres are in the angular points of the plan, and to terminate in a horizontal ridge parallel to the sides of the severies, and in a vertical plane, bisecting each side of the plan.

Let STVW, *Plate* XXX, *fig.* 1, be a portion of the plan consisting of two severies STUX, XUVW, the points S, T, U, V, W, X, being the points into which the axis of the pillars are projected.

Bisect VW by the perpendicular *r*L, and bisect VU by the perpendicular *p*L. Draw the straight lines *uq*, *v*L, *wm*, *xn*, *yo*, radiating from V to meet the ridge lines *r*L and L*p* in the points *r*, *q*, L, *m*, *n*, *o*, and the arc *tz* described from *v* in the points *u*, *v*, *w*, *x*, *y*, and these lines will be the plans of the ribs for one quarter of a severy.

Suppose now the rib over *tr* to be given, and let this rib be *fig.* 2, which is here made double. The half *abc* is the rib which stands upon *r t*, the curve *bc*, *fig.* 2, and the plans *tr*, *uq*, *v*L, *wm*, *xn*, *yo*, *zp*, *fig.* 1, of the ribs are given by the architect in the plan and sections of the work: it is the workman's province to find the curvature of the ribs, and the formation of the stones for the ceiling.

For this purpose we shall suppose that the chords which are formed by the joints in the intrados upon the meeting of the rib over *tr* to be equal; therefore divide the curve *bc*, *fig.* 2, into equal parts, so as to admit of vault stones of a convenient size.

From the points 1, 2, 3, &c. *fig.* 2, in the arc *bc*, draw lines perpendicular to *ab* the base of the rib. Transfer the parts of the line *ab* to *rt*, *fig.* 1, and let A be one of the points representing *e*, *fig.* 3. In *fig.* 1, draw *ut* and produce *ut*, and L*r* to meet each other in the point 3. Draw the straight line AB radiating to the point 2, to meet the plan *uq* in B. Join *uv* and produce *vu*, and L*r* to meet in 3, and draw the straight line BC radiating from 2, to meet the plan *v*L in C. Join *vw*, and produce *vw* and L*p* to meet each other in H. Draw CD radiating to the point H, to meet *wm* in D. Join *wx* and produce *wx*, and L*p* to meet each other in I, and draw DE radiating to the point I, to meet *xn* in E. Find the points F and G in the same manner as each of the points B, C, D, E, have been found, and the compound line ABCDEFG will be the line of joints corresponding to the point 5, *fig.* 2. Find the lines corresponding to the other joints in the same manner. Transfer the divisions in the line *uq* to the base line of *fig.* 3, and draw lines perpendicular to the base as ordinates. Transfer the ordinates

of *fig.* 2 to their corresponding ordinate in *fig.* 3, and draw the curves which will complete the inner edge of the rib, *fig.* 3. In the same manner find the curve of the ribs, *figs.* 4, 5, 6, &c. which stand over the lines *v*L, *wm*, *xn*, &c.

Fig. 7 exhibits a part of the plan of a groin-ceiling, consisting of two severies when the plans of the piers are squares, of which the angular points terminate in the sides of the plan of each severy, and then we have only to find the diagonal ribs and those upon the narrow side of the severy. It must, however, be observed, both in *figs.* 1 and 7, that only one of the curves which belong to arches of the two sides of a severy can be given, the other must be found in the same manner as the curves of the intermediate ribs. In *fig.* 7 the plan of the joints has only two points of convergence, which are found by producing the side of the square which forms the plan of the pillars, and the plan of the ridge-lines, till they meet each other.

We shall now proceed towards the formation of the stones of the vaulting.

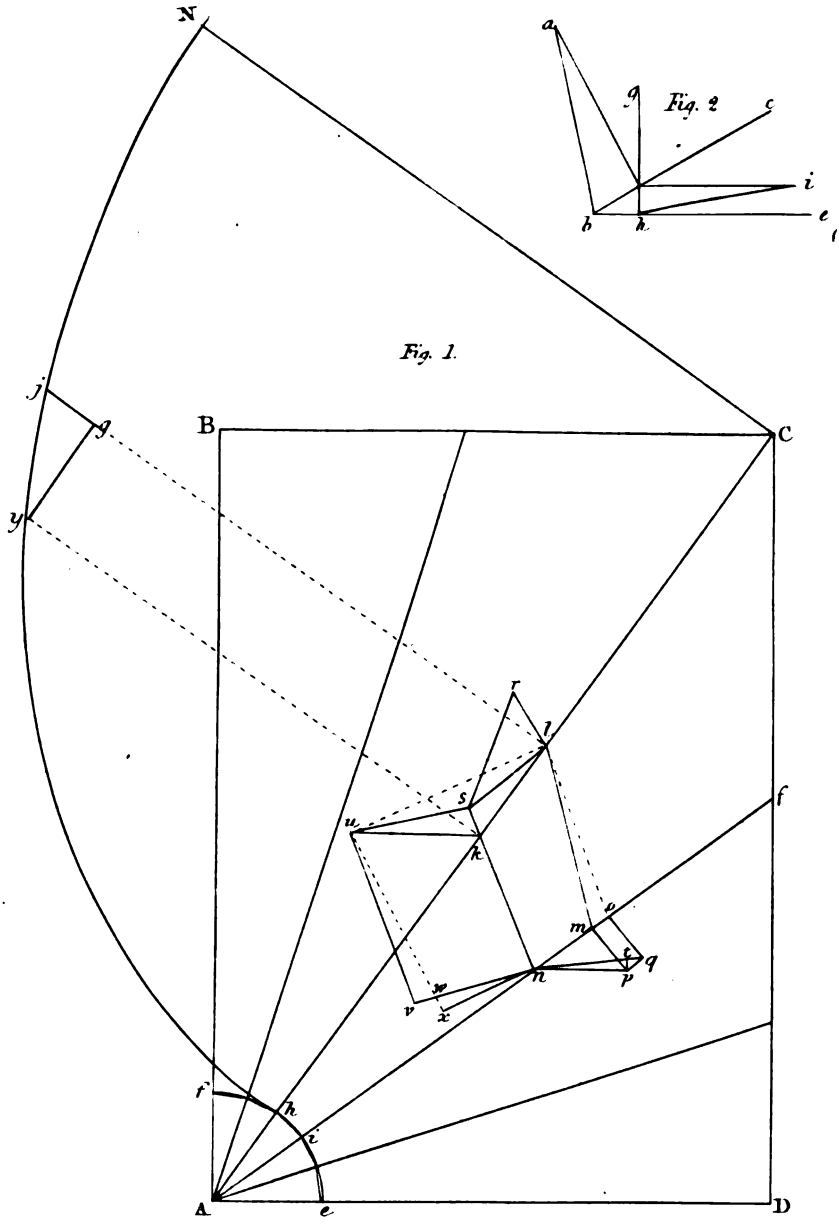
Plate XXXI. *Fig.* 1. Let ABCD be the plan of one quarter of a severy, and let *h*C and *if* be the seats of two adjacent ribs, and let *hyj*NC be the rib which stands upon *h*C, and let *klmn* be the plan of the soffit of a stone. Perpendicular to *h*C draw *ky* and *lj*, and draw *yg* parallel to *h*C. Produce *nk* to *s* and *nm* to *o*. Draw *lo* and *ls* respectively parallel to *sn* and *nm*. Draw *lr* perpendicular to *ls*; make *lr* equal to *gj*, and join *sr*. Draw *lu* perpendicular to *sn*; and from *s*, with the radius *sr*, describe an arc meeting *lu* in the point *u*. Draw *uv* and *nv* respectively parallel to *sn* and *su*. Perpendicular to *no* draw *oq* and *mp*. Make *oq* and *mp* each equal to *gj*, and join *np* and *nq*. Draw *pt* perpendicular to *nq*, meeting *nq* in the point *t*. To form the winding surface of the intrados, first work the soffit as a plane surface; on the plane surface describe the *figs. usnv*. Make *nw* equal to *nt*.

In *fig.* 2 make the angle *abc* equal to *sno*, *fig.* 1, and make the angle *cbe*, *fig.* 2, equal to *onq*. Having the two legs *cba*, *cbe* of a right-angled trehedral, find the angle *ghi*, which the hypothenuse makes with the leg *cbe*. Secondly, form the bed of the stone to make an angle at the arris-line *nv* with the surface *usnv*, equal to the angle *ghi*, *fig.* 2. Draw *wx* upon the end of the stone thus formed perpendicular to *nw*, and make *wx* equal to *tp*, and on the end of the stone draw *nx*. Join *ku*; then the four points *n*, *k*, *u*, *x*, are the four angular points of the soffit of the stone. The other end of the stone will be formed in a similar manner.

On the nature and construction of Gothic ceilings.

Let A, B, C, D, *Plate* XXXII, be the springing points, AC and BD the plans of the groins disposed in the vertices of the angle of a rectangle, their plans bisecting each other in the point *e*; also let QU and SX, passing through the point *e*, and bisecting the angles A*e*B, B*e*C, C*e*D, D*e*A, be the plans of the ridges of the gothic arches, and let AE, AH, BJ, BK, CM, CN, DP, DG, be the springing lines of the gothic ceiling.

Moreover, let the four straight lines EG, HJ, KM, NP, at right angles to QU and SX, be the plans of four right sections to each wing of the groined vault;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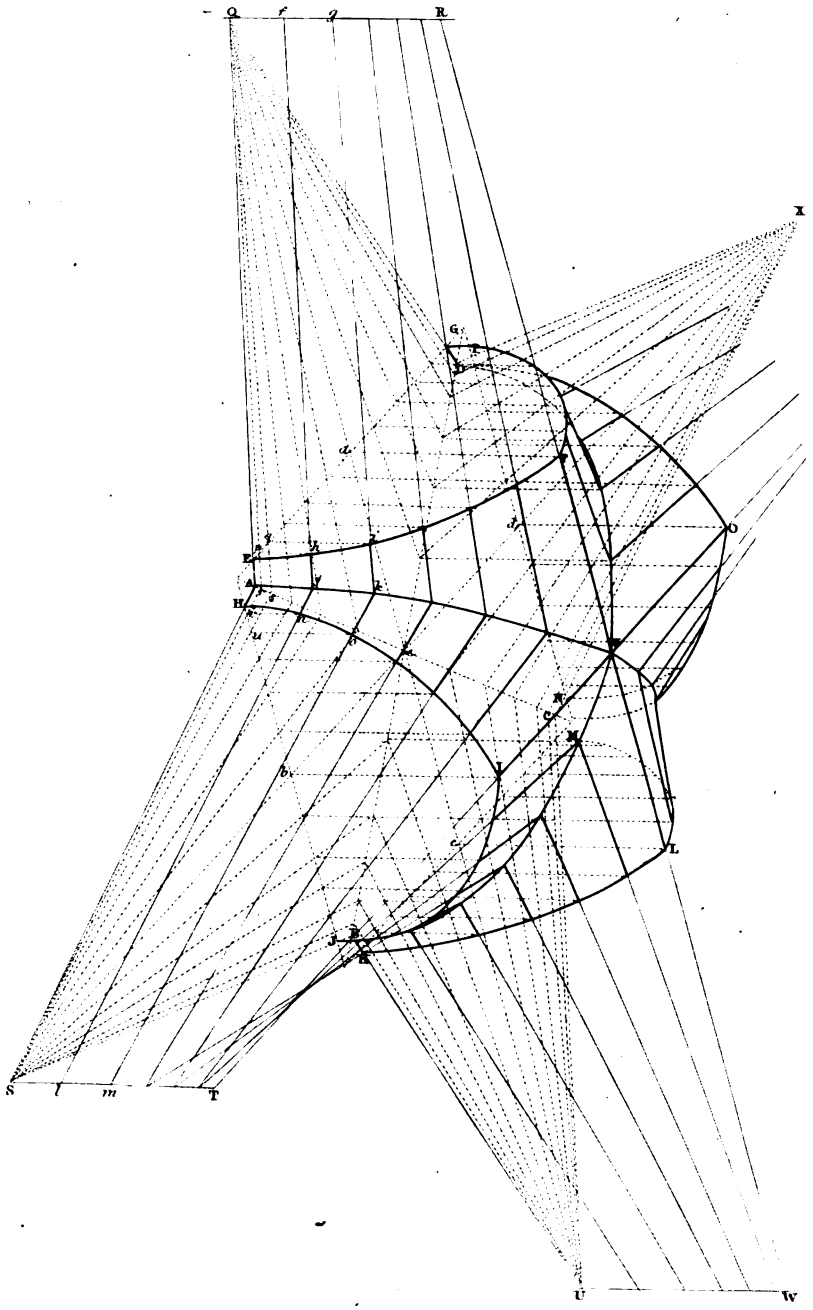
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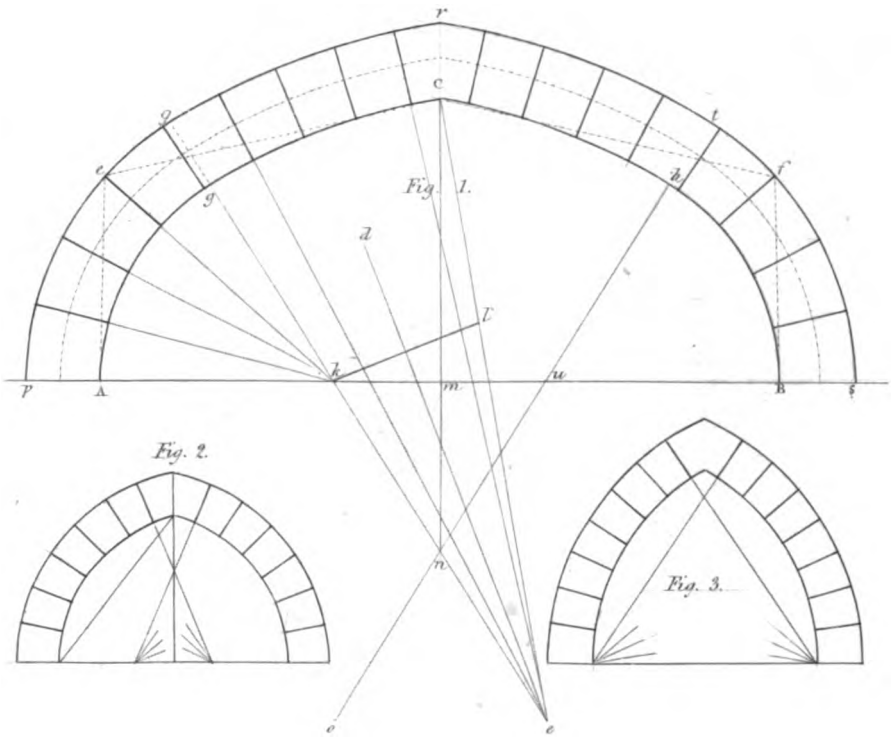
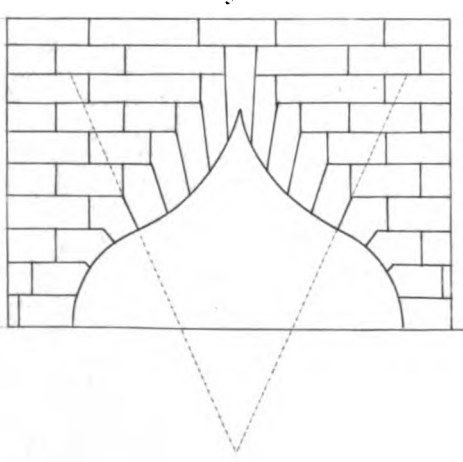
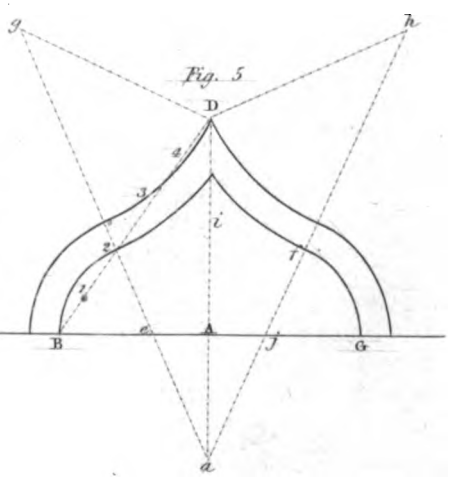


Fig. 2.

Fig. 4.





From the point *k*, as a centre with the radius *kp*, describe the arc *hg*; and and let the springing-lines AE, DG, AH, JB, &c. be such as to meet respectively in the points Q, S, &c.

To construct the ribs which are at right angles to the ridge-lines, and of which their plans are EG, HJ, &c. Let us suppose that the given rib is EFG, standing upon EG as its plan. Prolong AE and DG to meet each other in the point Q. Divide the half curve EF of the arch into as many equal parts as the number of courses is intended to be in the ceiling on each side of the ridge-line of the intrados of the arch; let us suppose that this number is six, and that *h* is the first point of division from the bottom point E of the rib, the succession of parts being E*h*, *hi*, &c. From the points *h*, *i*, &c. draw the straight lines *hp*, *iq*, &c. perpendicularly to EG, meeting EG in the points *p*, *q*, &c. Through the joints *p*, *q*, &c. draw from the point Q the lines Q*r*, Q*s*, &c., meeting AC, the plan of the groin in the points *r*, *s*, &c., and perpendicularly to AC draw the straight lines *rj*, *sk*, &c. Make *rj*, *sk*, &c., each respectively equal to *ph*, *qi*, &c. through the points A, *j*, *k*, &c., draw the curve A*jk*V for one half of the curve of the groin rib, the other half is symmetrical, and therefore the same curve in a reversed order.

To find the rib HIJ. Prolong AH and BJ to meet each other in the point S, and draw the lines *r*S, *s*S, &c. intersecting HJ in the points *t*, *u*, &c. Draw *tn*, *uo*, &c. perpendicular to HJ, and make *tn*, *uo*, &c. respectively equal to *ph*, *qi*, &c. Through the points H, *n*, *o*, &c. draw the curve HI, and HI will be the curve of one-half of the arch over the line HJ for the plan.

Hence we see that the lines *jh*, *ki*, &c. prolonged will meet the line QR perpendicular to the plane ABCD in the points *f*, *g*, &c. at the same heights Q*f*, Q*g*, &c. as *ph*, *pi*, &c. of the heights of the ordinates of the given rib. Since both sides are symmetrical, one description will serve each of them.

To describe a gothic isosceles arch to any width, height, and to a given verticle angle.

Plate XXXIII. Let AB, *fig.* 1, be the span or width of the arch; *m*C, perpendicular to AB, from the middle point *m*, the height; and *eCf* the vertical angle given by the tangents C*e* and C*f*, making equal angles with the line of height *m*C.

In this example, the points *e* and *f*, the lower extremities of the tangents, are regulated by erecting A*e* and B*f*, each perpendicular to AB, and making each equal to 3-4 of the height line, *m*C.

From the point A, towards B, make A*k* equal to A*e* or B*f*, that is equal to 3-4 *m*C; and from the point C, the vertex of the arch, draw C*e* perpendicular to C*i*. In C*i* take C*l*, equal to A*k*, and join *kl*; bisect *kl* by a perpendicular, *di* meeting C*i* in the point *i*; join *ik*, and produce *ik* to *g*.

From the point *i*, with the radius *i*C, describe an arc C*g*, meeting the line *ig* in the point *g*, and from the point *k*, with the radius *kg*, describe an arch *g*A, and A*g*C will be the one half of the intrados of the gothic arch required.

Produce C*m* to meet *ki* in the point *n*, and in AB make *mu* equal to *mk*, join *nu*, and prolong *nu* to *t*, and *un* to *o*. Make *no* equal to *ni*. From the centre *o*, with the radius *o*C, describe the arc C*h*, meeting *ut* in the point *h*, and from *u*, with the radius *uh*, describe the arc *h*B, and B*h*C will be the other half of the intrados.

Upon AB, prolonged both ways to *p* and *s*, make A*p* and B*s* each equal to the length of each one of the arch-stones in a direction of a radius.

From the point *k*, as a centre with the radius *kp*, describe the arc *pg*, and from the point *i*, with the radius *ig*, describe the arc *gr*, and *pgr* will be half of the extrados of the arch.

In the same manner will be formed *str*, the other half of the extrados. The arch-stones are divided upon the dotted line in the middle into equal parts, and the point lines are drawn by the centres of the intrados and extrados of the arch.

REMARK.

When the height of the arch is equal to, or greater than half the span, and when it is not necessary that the vertical angle should be given, the curves of the intrados and extrados on the one side may be described from the same centre, as also those of the other side from another centre.

The most easy gothic arch to describe, is that of which the height of the intrados is such as to be the perpendicular of an equilateral triangle, described upon the spanning line as a base, such is *fig.* 2, and these centres are the points to which the radiating joints must tend.

Gothic arches seldom exceed in height the perpendicular of the equilateral triangle inscribed in the intrados of the aperture; but when the arch is surmounted, and the height less than the perpendicular of the equilateral triangle made upon the base, draw a straight line from one extremity of the base to the vertex, and bisect this line by a perpendicular. From the point where the perpendicular meets the base of the arch, and with a radius equal to the distance between this point and the extremity of the base joined to the vertex, describe an arc between the two points, joined by the straight line, and the curve which forms one side of the intrados will be complete. In the same manner will be formed the curve on the other side, *See fig.* 3, so that by only two centres the whole of the intrados will be formed.

Fig. 4 and 5 shew the method of erecting another form of gothic arches.

Fig. 4, represents the manner of inserting the stone in a straight wall, so as to form a circular pointed arch.

Fig. 5, shows the manner of forming the same arch. Let BC be the base line of the arch; find the centre A, of BC; at A erect the perpendicular AD, the intended height of the arch; find *i* the centre of AD, produce AD, to *a* and make A*a* equal to A*i*; join BD, and divide it into five equal parts at 1, 2, 3, 4, 5. Draw the line *a* 2 through the point *e*, produce *a* 2 to *g*, make *g* 2 equal to *a* 2, and *e* and *g* will be the radiating points. From the point *e* with the radius *e*B describe the arc B2, and from the point *g* with the radius *g*D, describe the arc D2, and B2 will be the intrados of one portion of the arch, and D2, the extrados of the other corresponding portion of the arch. The extrados and intrados of the remaining side may be found in the same manner.

Fig. 1.

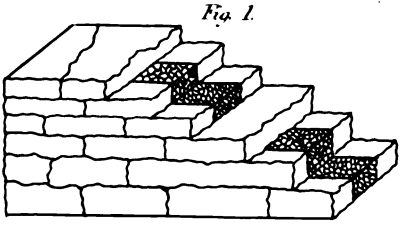
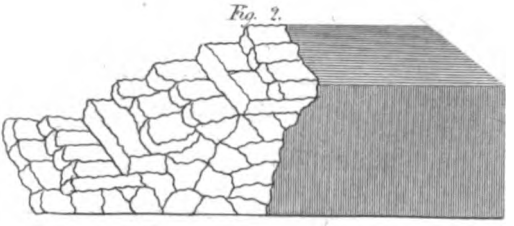


Fig. 2.



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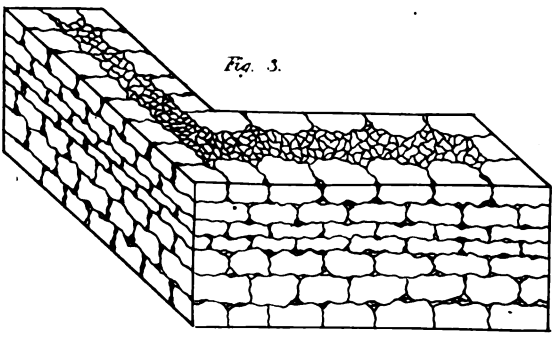

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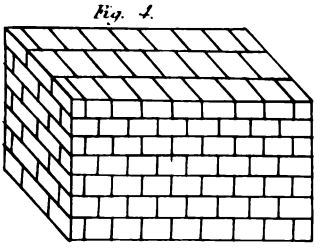


Fig. 5.

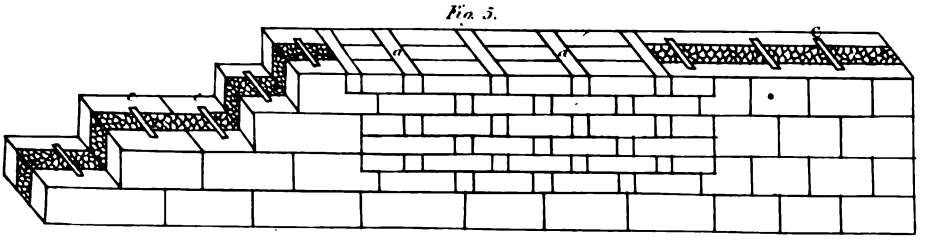
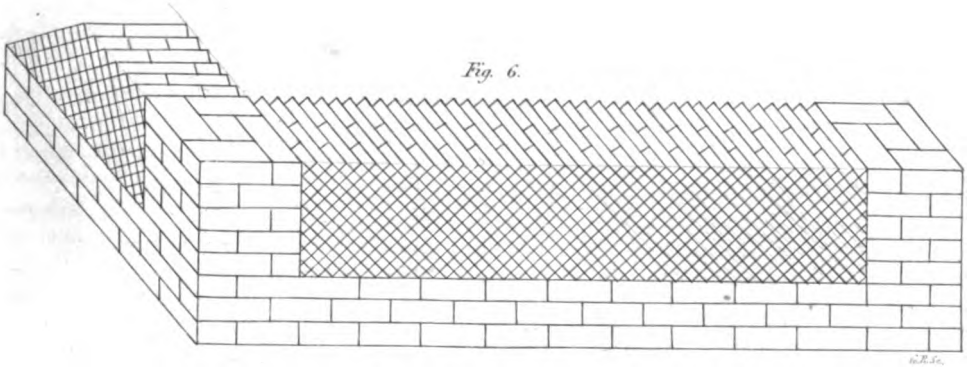


Fig. 6.



CHAPTER V.

SECTION I.

The ancients used several kinds of walls, in which more or less masonry was always introduced. They had their *incertain*, or *inserted* walls—and also their *reticulated* walls.

The uncertain or irregular walls are those where the stones are laid with their natural dimensions, and their figure and size of course uncertain. *Plate* 34, *fig.* 1. The materials rest firmly one upon another, and are interwoven together, so that they are much stronger, than the reticulated, though not so handsome. In this kind of wall, the courses were always level; but the upright joints were not ranged regularly or perpendicularly to each other in alternate courses, nor in any other respect correspondently; but uncertainly according to the size of the bricks or stones employed. Thus our bricks are arranged in ordinary walls in which all that is regarded is, that the upright joints, in two adjoining courses, do not coincide. Walls, of both sorts, are formed of very small pieces, that they may have a sufficient of, or be saturated with mortar, which adds greatly to their solidity.

To saturate, or fill up a wall with mortar, is a practice which ought to be had recourse to in every case, where small stones, or bricks, admit of it. It consists in mixing fresh lime with water, and pouring it, while hot, among the masonry in the body of the wall.

The walls called by the Greeks *Isidomum*, *fig.* 4, are those in which all the courses are of equal thickness; and *Pseudo-isidomum*, or false, fig. 3, when the courses are unequal. Both these walls are firm, in proportion to the compactness of the mass, and the solid nature of the stones, so that they do not absorb the moistness of the mortar; and being situated in regular and level courses, the mortar is prevented from falling, and thus the whole thickness of the wall is united. In the wall called complecton, fig. 2, the faces of the stones are smooth; the other sides being left as they came from the quarry, and are secured with alternate joints and mortar, the face of this wall was often covered with a coat of plaster. This kind of building called Diamixton, *fig.* 5, admits of great expedition, as the artificer can easily raise a case or shell for the two faces of the work, and fill the intermediate space with rubble-work and mortar. Walls of this kind, consequently, consist of three coats; two being the faces and

one the rubble core, which is the middle ; but the great works of the Greeks were not thus built, for in them, the whole intermediate space between the two faces, was constructed in the same manner as the faces themselves : and they besides occasionally introduced *diatonos*, or single pieces, extending from one face to the other, to strengthen and bind the wall, *fig.* 5. *a a.* These different methods of uniting the several parts of the masonry of a wall, should be well considered by all persons, who are entrusted with works requiring great strength and durability.

If the walls are *Isidomoi*, and fastened together with iron, they are properly called *cramped*, *fig.* 5. *c. c. c.* The net-work structure, fig. 6, was much used in ancient Rome, and is beautiful to the sight, but is liable to crack, wherefore no ancient specimens of this kind remain.

Plate XXXV. *fig.* 1, exhibits a species of ancient walls which may be seen at Naples. There are two walls A. A. of square stones, four feet thick ; their distance six feet. They are bound together by the transverse walls B. B. at the same distance. The cavity C C. left between, is six feet square, and is filled up with rubble stones and earth.

Fig. 2 represents a second kind, built of square stones, this was called *Pseudisodomum* D D ; to be seen now at Rome in the temple of Augustus. The third species is the *uncertain*, *fig.* 3 ; a specimen of which still remains at Palestrina, twenty miles east of Rome. Another kind, *fig.* 4, which may be seen at Sirmion upon the lake of Garda, is a species of wooden walls, E E, and are called Formae ; they are stuffed with stone mortar, &c. at random. The planks being taken away the wall F E. appears ; and is called formaceous.

The fifth kind, *fig.* 5, are walls made of cement, G G. composed of rough pebbles out of a river or from a rock ; sometimes of shell, as are the walls of Turin in Piedmont. This kind of wall should be bound by three courses of bricks, at the height of two feet, as H.H.

The sixth kind is brick-work ; *fig.* 6, which especially in the walls of a city, or extraordinary building, is constructed like the *Diamixton*, for the bricks appear, I. I. and the rubbish lies concealed in the middle, KK. In the bottom there are six courses of larger bricks ; then some less, at the height of three feet ; then the walls are bound again with three courses of larger bricks ; an example of this kind still remains in the Pantheon, and in the hot-baths built by Diocletian.

The seventh kind, *fig.* 7 is net-work L.L : which Palladio did not approve of, and to ensure the strength ofwhich, he proposed to erect buttresses at the angles M.M. and to place transversely, or lengthwise, six courses of bricks at the bottom N.N. and in the middle three courses O.O. whenever the net work is raised six feet.

The existing examples of Roman *emplecton*, with partial cores of rubble-work, or brick, sufficiently prove its durability ; but that of the Greeks was worked throughout the whole thickness of the wall, in the same manner as the facing of the fronts, as their temples now existing testify.

The thickness of walls should be regulated according to the nature of the materials, and the magnitude of the edifice. Walls of stone may be made one fifth thinner than those of brick ; and brick-

Fig. 1.

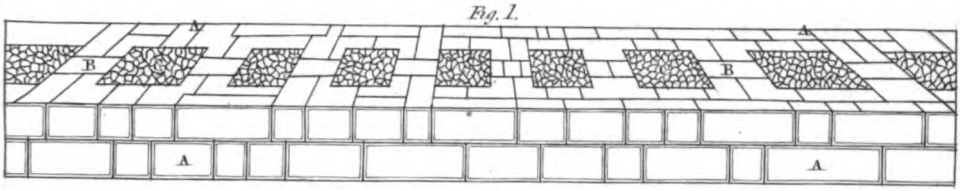
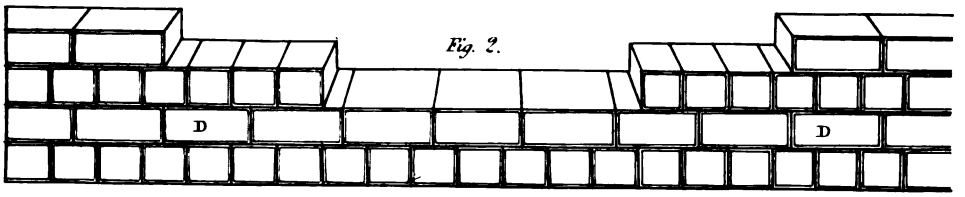


Fig. 2.



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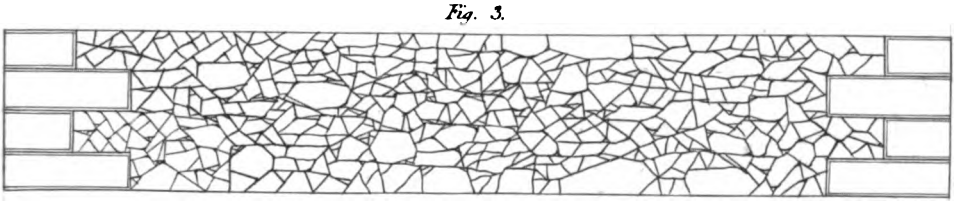

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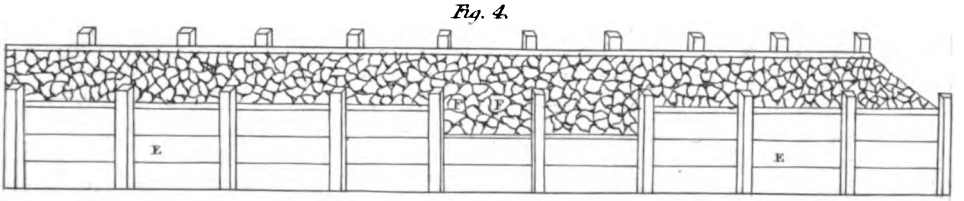

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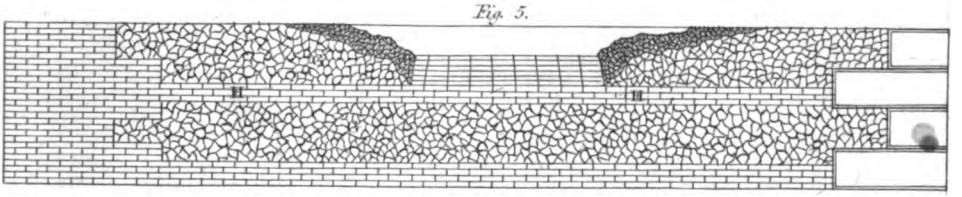

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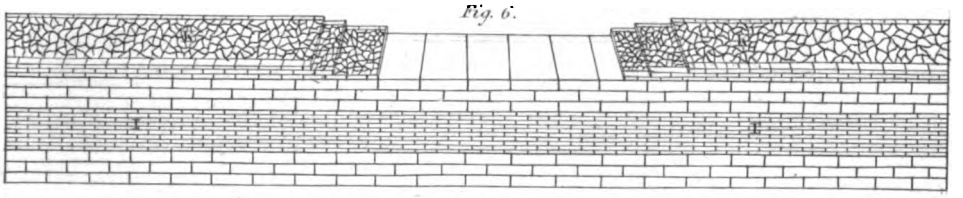

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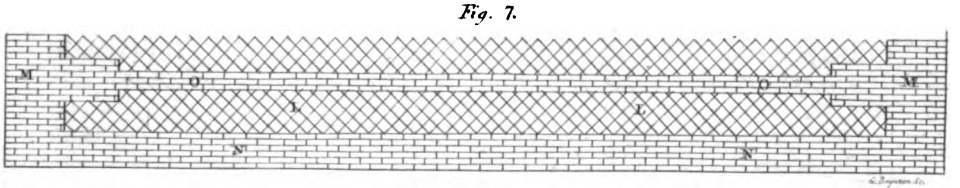

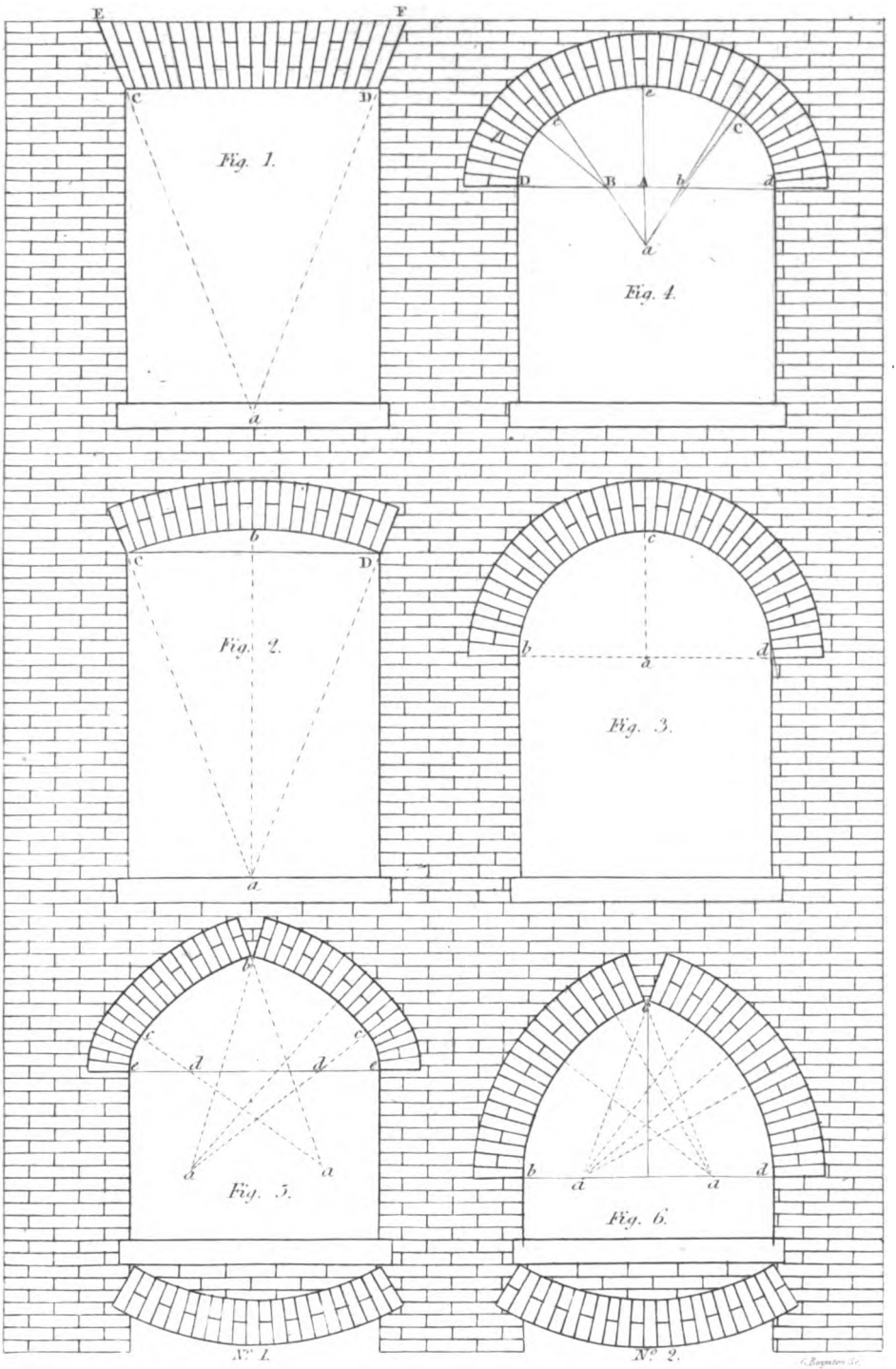
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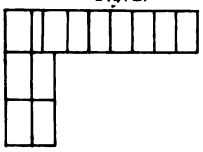
Fig. 1.



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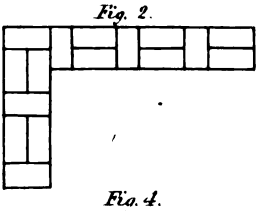

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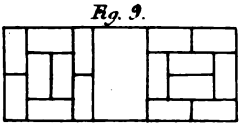

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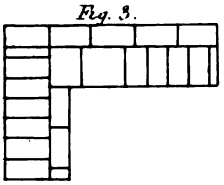

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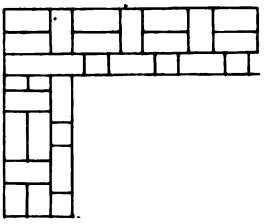

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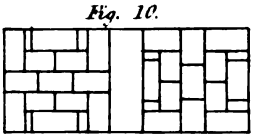
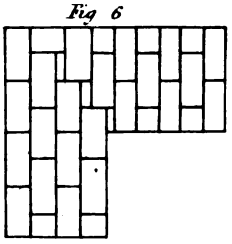


Fig 6



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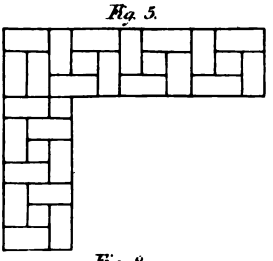

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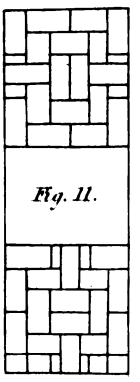

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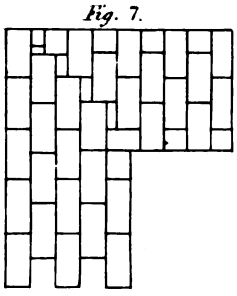

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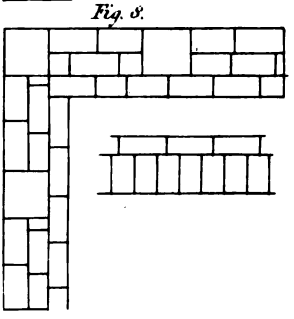

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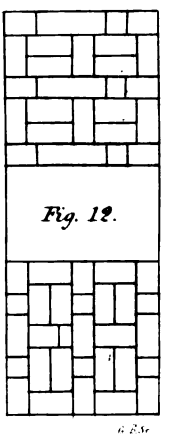

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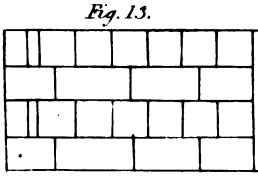

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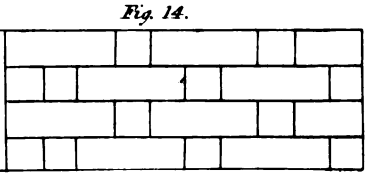


walls, in the basement and ground stories of buildings of the first rate, should be reticulated with stones, to prevent their splitting; a circumstance which has been two much disregarded by our builders.

SECTION II.——Construction of Brick Arches.

Plate XXXVI, *fig.* 1, represents a straight arch or aperture in a brick wall. Describe an isosceles triangle on C.D. the width of the arch as a base line whose vertex will be at *a*, produce *a* C. to E. and a D to F. and EF will be extrados, and CD the intrados of the arch.

Divide CD, and EF in to the same number of equal parts, and make the bricks to correspond with these parts.

Fig. 2 is a segment arch. Describe an isosceles triangle as in *fig* 1. and bisect CD. in *b.*; from the point *a*, with the radius *a* D describe the arc D*b*C. and with the radius *a* C produced from the point *a* describe the extrados and C *b* D, will be the intrados of the arch.

Fig. 3 is a semicircular arch; the intrados of which is easily found by making the semidiameter or ½ the width of the arch, the radius of the semicircle *b* ₰D.

Fig. 4 is a semileptical arch, formed from three points. Divide D*d* the width of the arch into three equal parts at the points *B*.l. from the centre A of D*d* erect the perpendicular A*e*, and produce A*e* at pleasure join Ba, making Ba equal to AD; produce aB to *c*, at the point B, with the radius B*c*; describe the arc *ed*; join *ba*, and produce ba. to C. then with the radius ac at the point a, describe the arc *c e* C, and at the point *b* with the radius *bd* describe the arc C *d* and the D, e d. the intrados of the intended arch will be complete.

Figs. 5 and 6 show the construction of Gothic arches on the principles laid down in the Plate 33. *fig.* 1 and 3.

Nos. 1 and 2 represent the application of inverted arches to the foundations of brick wall. *See foundations.*

SECTION III.——Bricklaying.

Bricklaying is the art of building with bricks, or the uniting them, by cement or mortar, into various forms for particular purposes.

Bricks are laid in a varied, but regular, form of connection, or *bond*, as exhibited in *Plates* 37 and 38. The mode of laying them for an 8 inch walling, shown in *fig.* 1 being denominated *English bond*; and *fig.* 2 *Flemish bond*. *Fig.* 3 is English bond, in a brick and a half, or 12 inch walling; and *fig.* 4, Flemish Bond, in the same. *Fig.* 5 represents another method of disposing flemish bond in a 12 inch wall. *Fig.* 6 English bond in a 16 inch, or a two brick thick wall; and *fig.* 7, English bond, in a two and a half brick thick wall.

Fig. 8 is another Brick bond, which is admired for its regularity and strength, it is formed of brick and tiles, and connected with this *fig.* is the next course above the tiles, composed of headers.

Figs. 9, 10, 11, 12, represent square courses, inpairs of Flemish bond. In each pair, if one be the lower course, the other will be the upper course.

The bricks having their lengths in the thickness of the wall, are termed *headers*, and those which have their lengths in the length of the wall are *stretchers*. By a *course*, in walling, is meant the bricks contained between two planes parallel to the horizon, and terminated by the faces of the wall. The thickness is that of one brick with mortar. The mass formed by bricks laid in concentric order, for arches or vaults, is also denominated a *course*.

The disposition of bricks in a wall, of which every alternate course consist of *headers*, and of which every course between every two nearest courses of headers consist of *stretchers*, constitutes English bond.

The disposition of bricks in a wall (except at the quoins) of which every alternate brick in the same course is a *header*, and of which every brick between every two nearest header is a stretcher, constitutes *Flemish bond*.

It is, therefore, to be understood that *English bond* is a continuation of one kind throughout, in the same course or horizontal layer, and consists of alternate layers of headers and stretchers, as shown in the plate; the headers serving to bind the wall together in a longitudinal direction, or lengthwise, and the stretchers to prevent the wall splitting crosswise, or in a transverse direction. Of these evils the first is of the worst kind, and therefore the most to be feared.

It is supposed, that the old English mode of brick-work affords the best security against such accidents; as work of this kind, wheresoever it is so much undermined as to cause a fracture, is not subject to such accidents, but separates, if at all, by breaking through the solid brick, just as if the wall were composed of one piece.

The ancient brick-work of the Romans was of this kind of bond, but the existing specimens are very thick, and have three, or sometimes more courses of brick laid at certain intervals of the height, stretchers on stretchers, and headers on headers, opposite the return wall, and sometimes at certain distances in the length, forming piers, that bind the wall together in a transverse direction; the intervals between these piers were filled up, and formed panels of rubble or reticulated work; consequently great substance, with strength, were economically obtained.

It will, also, be understood *Flemish bond* consists in placing, in the same course, alternate headers and stretchers, a disposition considered as decidedly inferior in every thing but appearance, and even in this, the difference is trifling; yet, to obtain it, strength is sacrificed, and bricks of two qualities are fabricated for the purpose; a firm brick often rubbed, and laid in what the workmen term a putty-joint for the exterior, and an inferior brick for the interior, substance of the wall; but, as these did not correspond in thickness, the exterior and interior surface of the wall would not be otherwise connected together than by an outside heading brick,

Fig. 1.

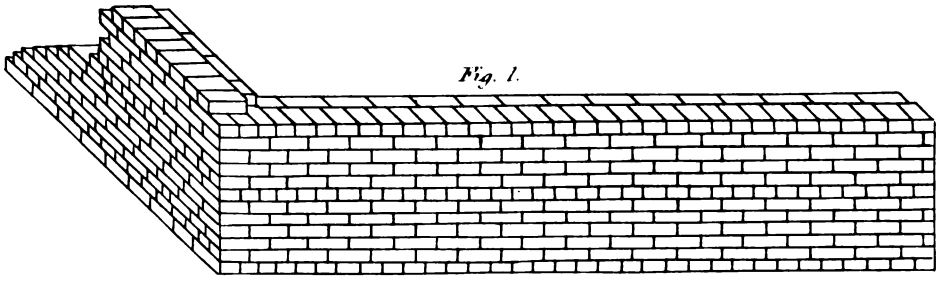


Fig. 2.

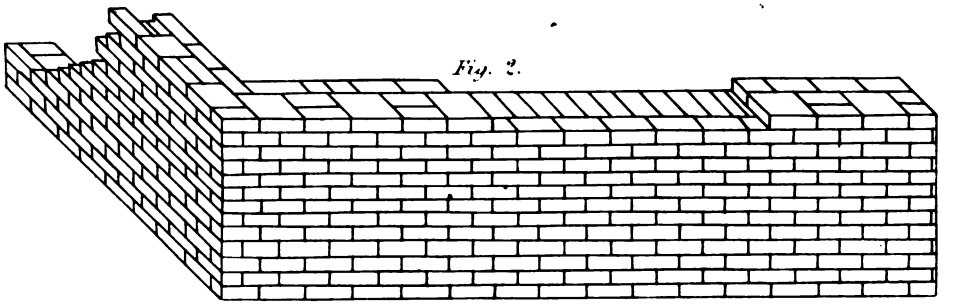


Fig. 3.

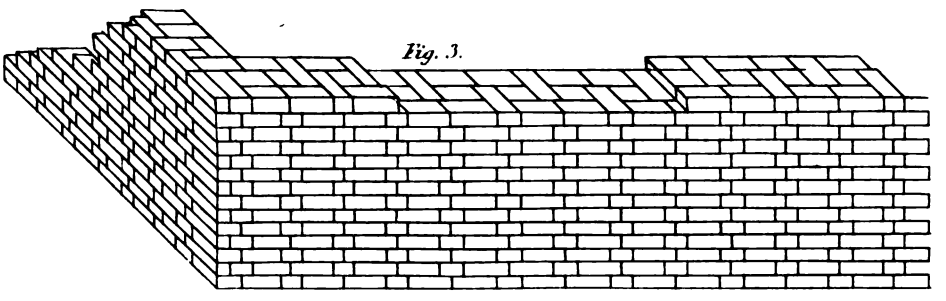
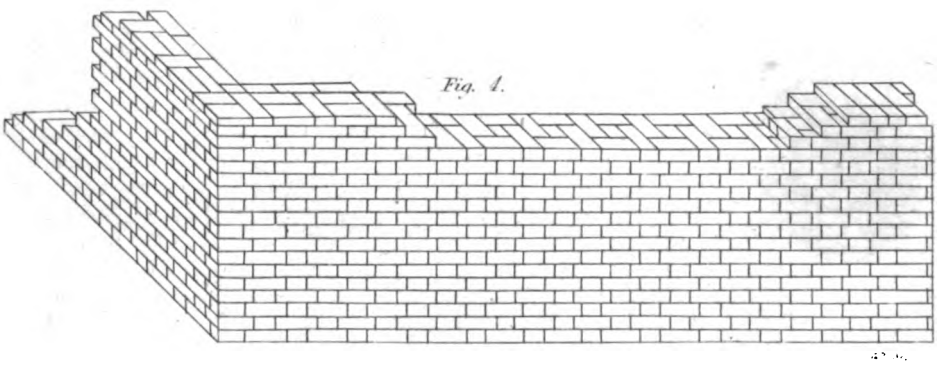


Fig. 4.



here and there continued of its whole length; but, as the work does not admit of this at all times, from the want of agreement in the exterior and interior courses, these headers can be introduced only where such a correspondence takes place, which, sometimes, may not occur for a considerable space.

Walls of this kind consist of two faces of four inch work, with very little to connect them together, and what is still worse the interior face often consists of bad brick, little better than rubbish. The practice of Flemish bond has, notwithstanding, continued in England, from the time of William and Mary, when it was introduced, with many other Dutch fashions, and the workmen are so infatuated with it, that there is now scarcely an instance of the old English bond to be seen.

The frequent splitting of walls into two thicknesses has been attributed to the Flemish bond alone, and various methods have been adopted for its prevention. Some have laid laths or slips of hoop iron, occasionally, in the horizontal points between the two courses; others have laid diagonal courses of bricks at certain heights from each other; but the effect of the last method is questionable, as in the diagonal course, by their not being continued to the outside, the bricks are much broken where the strength is required.

Other methods of uniting complete bond with Flemish facings have been described, but they have been found equally unsuccessful. In *figs.* 3 and 4 *Plate* 38 the interior bricks are represented as disposed with intention to unite these two particulars; the Flemish facings being on one side of the wall only; but this, at least, falls short of the strength obtained by English bond. Another evil attending this disposition of the bricks is, the difficulty of its execution, as the adjustment of the bricks in one course must depend on the course beneath, which must be seen or recollected by the workman; the first is difficult from the joints of the under course being covered with mortar, to bed the bricks of the succeeding course; and for the workman to carry in his mind the arrangement of the preceding course can hardly be expected from him; yet, unless it be attended to, the joints will be frequently brought to correspond, dividing the wall into several thicknesses, and rendering it subject to splitting, or separation. But, in the English bond, the outside of the last course points out how the next is to be laid so that the workman cannot mistake.

The outer appearance is all that can be urged in favour of Flemish bond, and many are of opinion, that, were the English mode executed with the same attention and neatness that is bestowed on the Flemish, it would be considered as equally handsome; and its adoption, in preference, has been strenuously recommended.

In forming English bond, the following rules are to be observed.

1st. Each course is to be formed of headers and stretchers alternately, as *fig.* 1.

2d. Every brick in the same course must be laid in the same direction; but in no instance, is a brick to be placed with its whole length along the side of another; but to be so situated that the end of one may reach to the middle of the others which lie contiguous

to it, excepting the outside of the stretching-course, where three-quarter bricks necessarily occur at the ends, to prevent a continual upright joint in the face-work.

3d. A wall, which crosses at a right-angle with another, will have all the bricks, of the same level course in the same parallel direction, which completely binds the angles, as shown by *figs.* 1, 3, and 6. *Plate* XXXVII.

The great principle in the practice of brick-work lies in the proclivity or certain motion of absolute gravity, caused by a quantity, or multiplicity of substances being added or fixed in resistible matter, and which, therefore, naturally tends downwards, according to the weight and power impressed. In bricklaying, this proclivity, chiefly by the yielding mixture of the matter of which mortar is composed, cannot be exactly calculated; because the weight of a brick, or any other substances laid in mortar, will naturally decline according to its substance or quality; particular care should be taken, therefore, that the material be of one regular and equal quality all through the building; and likewise, that the same force should be used to one brick as to another; that is to say, the stroke of the trowel, a thing or point in practice of much more consequence than is generally imagined; for if a brick be actuated by a blow, this will be a much greater pressure upon it than the weight of twenty bricks. It is, also, especially to be remarked, that the many bad effects arising from mortar not being of a proper quality should make masters very cautious in the preparation of it, as well as the certain quality of materials of which it is composed, so that the whole structure may be of equal density, as nearly as can be effected.

Here we may notice a particular which often causes a bulging in large flank walls, especially when they are not properly set off on both sides; that is, the irregular method of laying bricks too high on the front edge; this, and building the walls too high on one side, without continuing the other, often causes defects. Notwithstanding, of the two evils, this is the least; and bricks should incline rather to the middle of the wall, that one half of the wall may act as a shore to the other. But even this method, carried too far, will be more injurious than beneficial, because the full width of the wall, in this case, does not take its absolute weight, and the gravity is removed from its first line of direction, which, in all walls, should be perpendicular and united; and it is farther to be considered that, as the walls will have a superincumbent weight to bear, adequate to their full strength, a disjunctive digression is made from the right line of direction; the conjunctive strength becomes divided; and instead of the whole or united support from the wall, its strength is separated in the middle, and takes two lateral bearings of gravity; each insufficient for the purpose; therefore, like a man overloaded either upon his head or shoulders, naturally bends and stoops to the force impressed; in which mutable state the grievances above noticed, usually occur.

Another great defect is frequently seen in the fronts of houses, in some of the principal ornaments of brick-work, as arches over windows, &c., and which is too often caused by a want of experience in

rubbing the bricks; which is the most difficult part of the branch, and ought to be very well considered. The faults alluded to are the bulging or convexity in which the faces of arches are often found, after the houses are finished, and sometimes loose in the key or centre bond. The first of these defects, which appears to be caused by too much weight, is, in reality, no more than a fault in the practice of rubbing the bricks too much off on the insides; for it should be a standing maxim, (if you expect them to appear straight under their proper weight,) to make them the exact gauge on the inside that they bear upon the front edges; by which means their geometrical bearings are united, and tend to one centre of gravity.

The latter observation, of camber arches not being skewed enough, is an egregious fault; because it takes greatly from the beauty of the arch, and renders it insignificant. The proper method of skewing all camber arches should be one third of their height. For instance, if an arch is nine inches high, it should skew three inches; one of twelve inches, four; one of fifteen, five; and so of all the numbers between those. Observe, in dividing the arch, that the quantity consists of an odd number; by so doing, you will have proper bond; and the key bond in the middle of the arches; in which state it must always be, both for strength and beauty. Likewise observe, that arches are drawn from one centre; the real point of camber arches is obtained from the above proportion. First, divide the height of the arch into three parts; one is the dimension for the skewing; a line drawn from that through the point at the bottom to the perpendicular of the middle arch, gives the centre; to which all the rest must be drawn.

SECTION IV.—Foundations.

RULES TO BE OBSERVED IN LAYING FOUNDATIONS.

If a projected building is to have cellars, under-ground kitchens, &c. there will commonly be found a sufficient bottom, without any extra process, for a good solid foundation. When this is not the case, the remedies are to dig deeper; or to drive in large stones with the rammer; or by laying in thick pieces of oak, crossing the direction of the wall, and planks of the same timber, wider than the intended wall and running in the same direction with it. The last one to be spiked firmly to the cross-pieces to prevent their sliding, the ground having been previously well rammed under them.

The mode of ascertaining if the ground be solid is by the rammer; if by striking the ground with this tool, it shake, it must be pierced with a borer, such as is used by well-diggers; and having found how deep the firm ground is below the surface, you must proceed to remove the loose or soft part, taking care to leave it in the form of steps if it be tapering, that the stones may have a solid bearing, and not be subject to slide, which would be likely to happen if the ground were dug in the form of an inclined plane.

If the ground prove variable, and be hard and soft at different

places, the best way is to turn arches from one hard spot to another. Inverted arches have been used for this purpose with great success, by bringing up the piers, which carry the principal weight of the building, to the intended height and thickness, and then turning reversed arches from one pier to another, as shown in *figs.* 5 and 6, *plate* XXXVI, Nos. 1 and 2.

In this case, it is clear that the piers cannot sink without carrying the arches, and consequently, the ground on which they lie, with them. This practice is excellent in such cases, and should therefore be general, wherever required.

Where the hard ground is to be found under the apertures only, build your piers on those places, and turn arches from one to the other. In the construction of arches some attention must be paid to the breadth of the insisting pier, whether it will cover the arch or not; for, suppose the middle of the piers to rest over the middle of the summit of the arches, then the narrower the piers, the more curvature the supporting arch ought to have at the apex. When arches of suspension are used, the intrados ought to be clear, so that the arch may have the full effect; but, as already noticed, it will also be requisite here that the ground on which the piers are erected be uniformly hard; for it is better that it should be uniform, though not so hard as might be wished, then to have it unequally so; because in the first case, the piers would descend uniformly, and the building remain uninjured; but in the second, a vertical fracture would take place, and endanger the whole structure.

SECTION V.—Walls, &c.

The foundation being properly prepared, the choice of materials is to be considered. In places much exposed to the weather, the hardest and best bricks must be used, and the softer reserved for indoor work, or for situations less exposed.

If laying bricks in dry weather, and the work is required to be firm, wet your bricks by dipping them in water, or by causing water to be thrown over them before they are used. Few workmen are sufficiently aware of the advantage of wetting bricks; but experience has shown, that works in which this practice has been followed, have been much stronger than others, wherein it has been neglected. It is particularly serviceable, where work is carried up thin, and putting in grates, furnaces, &c.

In the winter season, so soon as frosty and stormy weather set in, cover your wall with straw or boards; the first is the best, if well secured, as it protects the top of the wall, in some measure, from frost, which is very prejudicial, particularly when it succeeds much rain; for the rain penetrates to the heart of the wall, and the frost, by converting the water into ice, expands it, and causes the mortar to assume a short and crumbly nature, and altogether destroys its tenacity.

In working up a wall, it is proper not to work more than four or five feet at a time; for, as all walls shrink immediately after build-

ing the part which is first brought up will remain stationary; and when the adjoining part is raised to the same height, a shrinking or setling will take place, and separate the former from the latter, causing a crack, which will become more and more evident, as the work proceeds.

In carrying up any particular part, each side should be sloped off, to receive the bond of the adjoining work on the right and left. Nothing but absolute necessity can justify carrying the work higher in any particular part, than one scaffold; for, wherever it is so done, the workmen should be answerable for all the evil that may arise from it.

The distinctions of *Bond* have already been shown, and we shall now detail them more particularly; refering to *Plate* XXXVII, in which the arrangement of bricks of different thickness, so as to form *English Bond*, is shown in *figs.* 1, 3, 6, and 7.

The bond of a wall 8 *inches* is represented by *fig.* 1. In order to prevent two upright or vertical joints from running over each other, at the end of the first stretcher from the corner, place the return-stretcher, which is a header, in the face that the stretcher is in below, and occupying half its length; a quarter brick is placed on its side, forming together 6 inches, and leave a lap 2 inches for the next header, which lies with its middle upon the middle of the header below, and forms a continuation of the bond. The three-quarter brick, or brick-bat, is called a *closer.*

Another way of effecting this, is by laying a three-quarter bat at the corner of the stretching course; for, when the corner head comes to be laid over it, a lap of 2 inches will be left at the end of the stretchers below for the next header; which, when laid, its middle will come over the joint below the stretcher, and in this manner form the bond.

In a 12 *inch, or brick-and-half wall,* (*fig.* 3,) the stretching course upon one side, is so laid that the middle of the breadth of the bricks, upon the opposite side, falls alternately upon the middle of the stretchers and upon the points between the stretchers.

In a two-brick wall, (*fig.* 6,) every alternate header, in the heading course, is only half a brick thick on both sides, which breaks the the joints in the core of the wall.

In a two-brick and a half wall, (*fig.* 7,) the bricks are laid as shown in *fig.* 6.

Flemish bond, for an eight inch wall, is represented in *fig.* 2, wherein two stretchers lie between two headers, the length of the headers and the breadth of the stretchers extending the whole thickness of the wall.

In a brick-and-half Flemish bond, (*fig.* 4,) one side being laid as in *fig.* 2, and the opposite side, with a half-header, opposite to the middle of the stretcher, and the middle of the stretcher opposite the middle of the end of the header.

Figure 5, exhibits another arrangement of Flemish bond, wherein the bricks are disposed alike on both sides of the wall, the tail of the headers being placed contiguous to each other, so as to form square spaces in the core of the wall for half-bricks.

The face of an upright wall, English bond, is represented by *fig.* 13 and that of Flemish bond, by *fig.* 14.

SECTION VI.

THE CONSTRUCTION OF CHIMNIES.

Many able and scientific men have treated on this subject, but the result of their observations serve only to prove, what is the object of every day's experience, namely, that rarefied air is lighter and less dense than cold air; and that it will ascend with a velocity proportionate to its rarefaction, unless obstructed by other bodies.

Heat, that is generated by the combustion of fuel, exists under two distinct forms; and is known by the names of combustible and radiant heat. Combustible heat partakes of smoke, and is carried off with it into the upper regions; while radiant heat is communicated to opposing bodies in contact with its rays.

It is stated by some that combustible heat combined with air and smoke exists in the proportion of four to one, compared to radiant heat; but its correct proportion has, perhaps, never been ascertained.

It is however certain, that very little radiant heat will escape from a smothered combustion, while a dense smoke will very slowly ascend, and sometimes a portion of it is discharged into the room, and the chimney is pronounced smoky, while the epithets uttered against masons, on such occasions, would be more properly applied to the builders of the fire.

As nature acts by certain laws, we may derive more profitable information by a proper observance of them, than from accidental occurrences.

It is one of the laws of nature, that rarefied air ascends, while cold or dense air descends. On the same principle water discharges itself most copiously through a channel of an uniform and direct surface, on the same inclination. Therefore, channels, that are obstructed by eddies, and the discharge of other streams into them, are impeded, and the velocity of the water diminished, so as often to produce what is called back-water for a considerable distance, which, when removed, permits the water to flow with rapidity. Short bends and turnings also present obstacles to the current or flow of water, by which whirlpools are often seen in actual contact with the natural stream. The same observations may be applied to rarefied air or smoke. Hence those flues will carry smoke the best which arise perpendicularly in an uniform direction.

Angles and turnings present obstacles to the progress of the smoke, and should be avoided as much as possible.

Particular attention should be paid to the formation of the throat of the chimney. The dimensions of which should in no case exceed the number of square inches contained in a horizontal section of the flue. It has been contended by some that it should be smaller

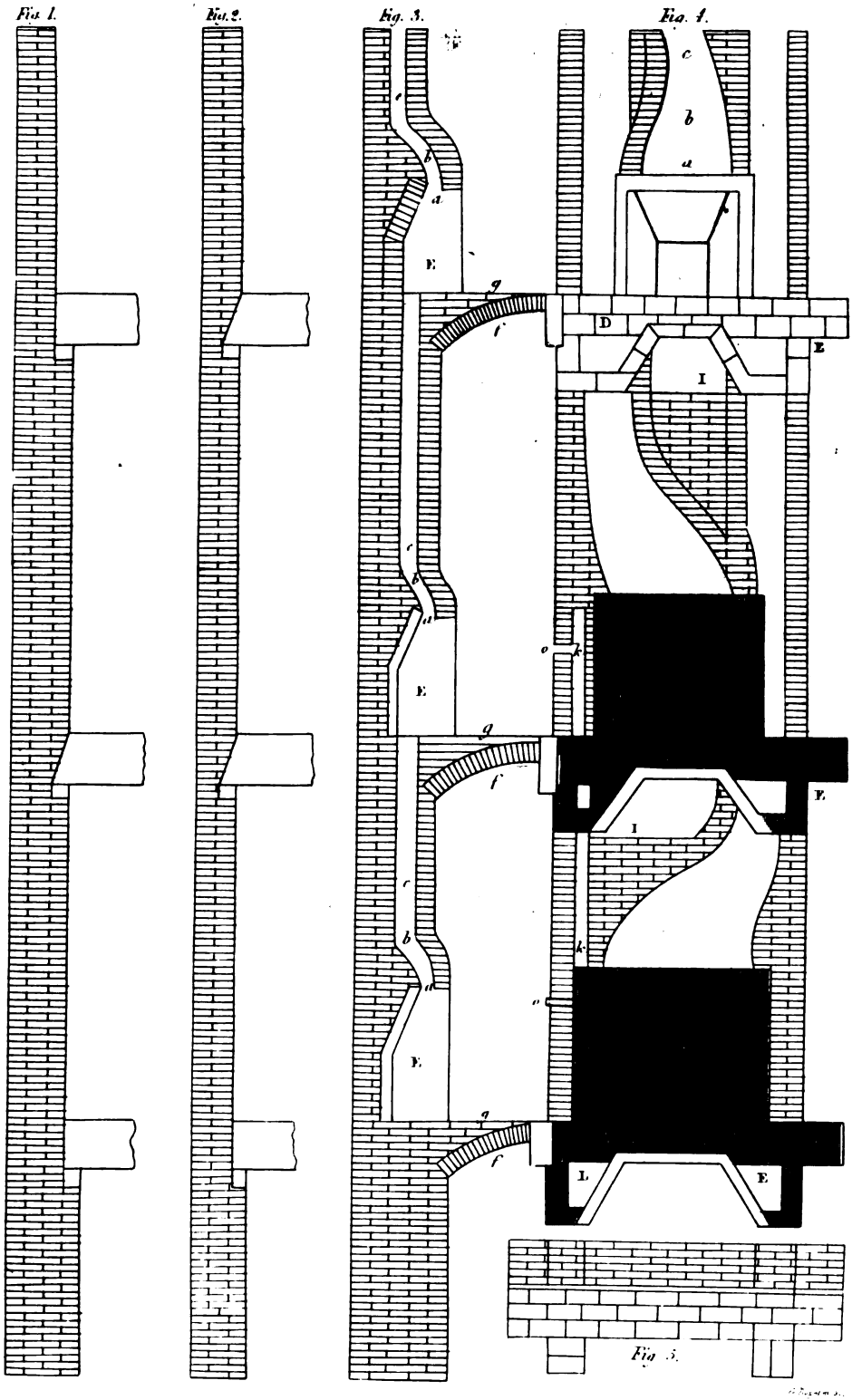


Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
c
b
a
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D
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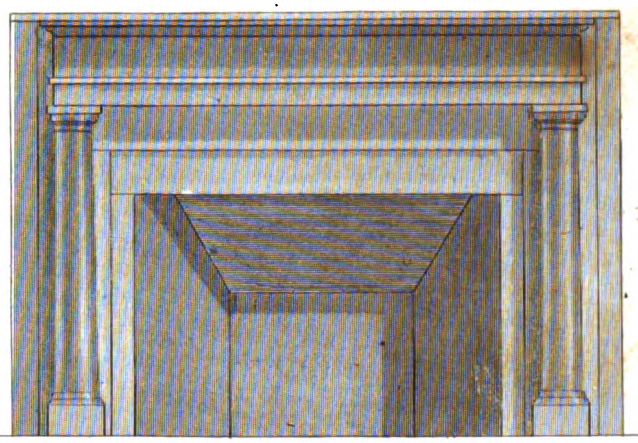
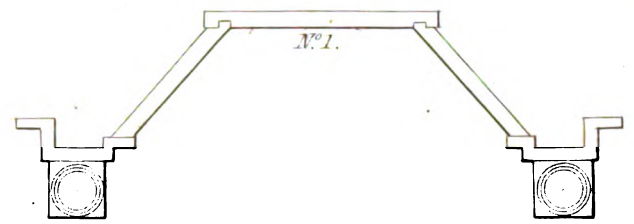
Fig. 5.

Fig. 1.

N°. 2.

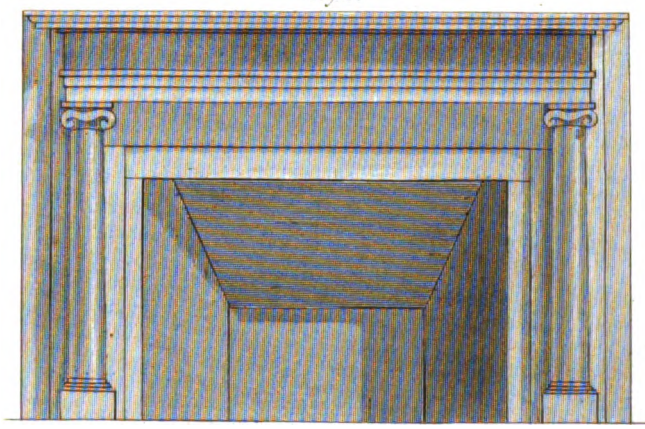


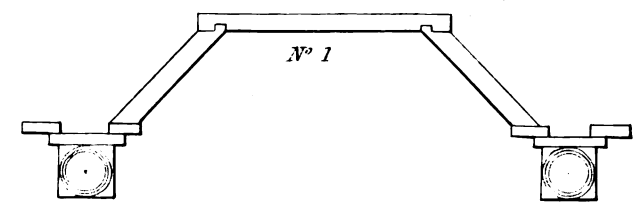


N°. 1.

Fig. 2.

N°. 2.





N° 1

than this, while others have thought that it should be larger; but experience has shown both of these opinions to be erroneous. When the throat is smaller, the frequent rushes of cold air into it, from the opening of doors, &c. sends a gush of smoke into the room, by obstructing the upward current of rarefied air.

When the throats are larger, eddies are formed in them, and the smoke, becoming dense by the steam of the fuel, choaks the flue, and instead of ascending, is puffed into the room.

Experience has shown the best construction to be that, where the throat contains as many square inches as a section of the flue. If the latter, for instance, is 144 inches, the throat should bc 4 feet long; and 3 inches wide nearly on a level with the mantle-bar, or at the top of the opening of the fire-place, and graduated to the regular dimensions of the flue.

As represented in *Plate* XXXIX, *figs.* 3 and 4. In this Plate, *fig.* 3 shows a side perpendicular section of a chimney; *d*, the partition wall; *a*, the throat; *b*, the breast; *c*, the height of the graduation to form the regular flue; E, the depth of the jamb; *f*, a trimmer to support the hearth in form of a segment arch.

Fig. 4 is the front elevation of *fig.* 3, representing the flues, fire-places, a horizontal section at the hearths, as DE; a section of the flues at the side of the fire-places I; the core of the chimney, H; the jambs F; the back of the fire-places G, with the inclined part of the back.

FIRE-PLACES.

In the selection of materials for the construction of fire-places, those should be preferred, which contain the least metallic ingredients. Metals are absorbents of heat, and consequently occasion less heat to be radiated into the room, than materials of a different nature. Soapstone has been found to be one of the best materials for this purpose. It contains but little metallic substance compared to brick; it is capable of a high degree of polish and of being easily kept clean, by which means the rays of heat are reflected into the room.

The proportions of a fire-place should in some degree be regulated according to the size of the room, for which it is intended to warm.

If the room is 18 feet in length, a fire-place of 4 feet 3 inches in width, from jamb to jamb; and 3 feet in height where the room is 12 feet in the same direction, or 1-4 of the height of the room, may, in general, be considered of suitable proportions. The jambs should form an angle of 135 degrees with the back. *See* Plate XXXIX, *fig.* 4, H the jamb, the back edge of which should be rabbited and fitted to a groove in the back to keep it in its place, F should be set plumb about 2-5ths of the height of the back FG; G should be inclined forward to within 7 inches of the front line, allowing 4 inches for the thickness of the breast, and 3 inches will remain for the passage of the smoke.

The communication of hot air to rooms. This subject is worthy of attention, in as much as the temperature of bed chambers may

be regulated by it, as well as the danger of fire, and the destructive and fatal effects of charcoal diminished. This improvement may be adapted to common fire-places as well as to grates, and the hot air carried from the first to the upper stories.

A little below the hearth in the first story, a small aperture is opened, of about 2 inches square, through which to receive fresh air from the outside of the house into a cavity, as large as can with convenience be made between the jambs and the brick, which form the wall of the chimney, this cavity should be made tight, with an aperture for the insertion of tubes of copper or tin, which are to be inserted in the aperture with stops or slides to regulate the quantity of air to be admitted into the room. The air enters about two feet from the floor. By turning the slide, the air is made to ascend into other apartments at pleasure.

Plate XXXIX, *fig.* 4, L, is the generator of rarefied air; *o* the tube with a slide at *k*; the ascending pipe should be about 4 inches square; *m* shows its passage at the hearth.

Chimney-pieces are of various forms, as the fancy or taste of the proprietor may dictate.

In Plate XL, *fig.* 1, is a doric chimney-piece. No. 1, a section of the jambs, back facing, flinth and pillars, drawn on a scale of 1-2 inch to a foot, No. 2 the shelf. *Fig.* 2 represents an Ionic chimney-piece; No. 1 a section; No. 2 the shelf; the line *a* shows a projection of the entablature; *b*, the facing under the entablature, drawn on a scale of 1-2 an inch to a foot.